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Report No. 20

DESIGN AND DEVELOPMENT OF A GAS-PARTICULATE FILTER UNIT FOR THE MAIN BATTLE TANK

Final Report

by
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November 1965

US Army Edgewood Arsenal
CHEMICAL RESEARCH AND DEVELOPMENT LABORATORIES
Edgewood Arsenal, Maryland 21010

Contract DA-18-035-AMC-100(A)

Protective Systems Department
Research and Development Division
DONALDSON COMPANY, INC.
Minneapolis, Minnesota 55431

FOREWORD

The work described in this report was authorized under Task 1B643606DO1806, Collective Protection System for the Main Battle Tank. The Feasibility Study Phase began in September 1963 and concluded in December 1964. Phase II, Fabrication and Test of prototypes and pre-production models, began 28 December 1964 and was concluded on September 31, 1965. The experimental data are contained in Notebooks EC1 through EC18 in the Contractor's files. The past 19 technical reports published under this contract include Monthly Progress Reports 1 through 13; a Design Study Report; a Feasibility Study Report; Bimonthly Progress Reports No. 16, 17, and 19; and Supplementary Report No. 18. This is the final report of this contract.

Acknowledgements

The development effort of this contract was performed by the Protective Systems Department, Research and Development Division of Donaldson Company, Inc., with the close support of the entire organization. Under the direction of T.A. Baden, as Program Manager, and M.R. Johnson, Assistant to Program Manager; principal effort was performed by K.J. Conklin, Project Engineer; D.O. Sata, Industrial Engineer; J.H. Scott, Project Engineer; D.W. Schoen, Design Engineer; E.E. Grassel, Senior Research Chemist; and N.E. Stenoien, Technical Writer. These key people were supported by Technicians, Designers, Technical Writers, Draftsmen, Value Analysts, and Quality Assurance personnel.

Notices

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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When this document has served its purpose DESTROY it.

DIGEST

Twenty-five months of design, development, and test of the E49 400 cfm EMD Tank Gas-Particulate Filter Unit intended for crew compartment air supply and pressurization of the proposed Main Battle Tank are summarized in this report.

The Filter Unit design was updated from the Breadboard Model, Working Model, and Optimum Development Models of the Feasibility Phase to the Preproduction Models during the Development Program Phase of Contract DA-18-035-AMC-100(A). Proving tests of performance and design were in accordance with the Contract with environmental resistance testing in accordance with Appendix A of this report.

The design and development program was successfully completed by meeting Contract objectives and intent. The results are evidenced by:

Design, fabrication, and test of twelve Preproduction Models of the E49 400 cfm EMD Tank Gas-Particulate Filter Unit.

Compilation of a Technical Data Package including Class I Drawings, Purchase Descriptions, Maintenance Package Manuals, Maintenance Support Planning Data, Inspection Aids Manuals, Packaging and Packing Instructions, and Training Aids and Lesson Plans.

Design and fabrication of inspection aid equipment for the control panel, gas filter, particulate filter, housing, fan, precleaner, deep-fording valve, and Filter Unit.

Successfully meeting performance, design, and reliability requirements through testing in accordance with Contract requirements.

The following conclusions support the design and performance of the E49 Filter Unit as conceived and developed for application to the proposed Main Battle Tank.

The E49 Filter Unit provides a minimum of 400 cfm of air; purified of dust, toxic aerosols, and gases; with a minimum output pressure of 1.0 inch of water for a minimum period of 24-hours continuous operation under worst battle conditions of dust, chemical, or biological exposure.

The E49 Filter Unit is equipped for sealing during deep-fording operations to 24-feet of water.

The E49 Filter Unit meets structural and performance requirements under ambient temperature extremes from -65°F to 155°F and under all shock

and vibration conditions which a tracked vehicle would encounter. In addition, performance is maintained during operation on 60 percent longitudinal and transverse slopes.

The E49 Filter Unit air delivery is controllable in the range of 135 to 400 cfm with a maximum current draw of less than 90 amps on 27.5 vdc power.

The E49 Filter Unit, a self-contained unit, has successfully met the operating requirements and environmental resistance requirements specified by Contract DA-18-035-AMC-100(A). The Filter Unit is remotely controlled by a control panel which can be located with the vehicle controls.

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OF A
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Final Report

I INTRODUCTION

This report summarizes and concludes the contractual effort of Project 1B643606DO1806 and Contract DA-18-035-AMC-100(A) covering development of a Gas-Particulate Filter Unit (Collective Protection Unit) for the proposed Main Battle Tank (MBT). The original contractual technical services period of performance was scheduled for a period of thirty-one (31) months commencing on 25 September 1963 and ending on 25 March 1966 with the final report completed by 31 May 1966. However, letter dated 1 June 1965 from Director of Procurement, partially terminated the above contract for the convenience of the Government. The subject contractual effort partially terminated were:

A Delete paragraph IG4 - MBT Integration Tests and Final Engineering and Service Tests (ET/ST) - Phase III.

B Delete paragraph IG5 - Retrofit of Systems and Finalization of Engineering Drawings and Documentation - Phase IV.

C Delete paragraph IG6 - Production Study - Phase V.

D Discontinue further development work under Modification No. 5 to the contract, dated 18 January 1965, relative to development of an Anti-Blast Closure for the Collective Protection System for the Main Battle Tank, and concurrent work in connection with the MICV-65.

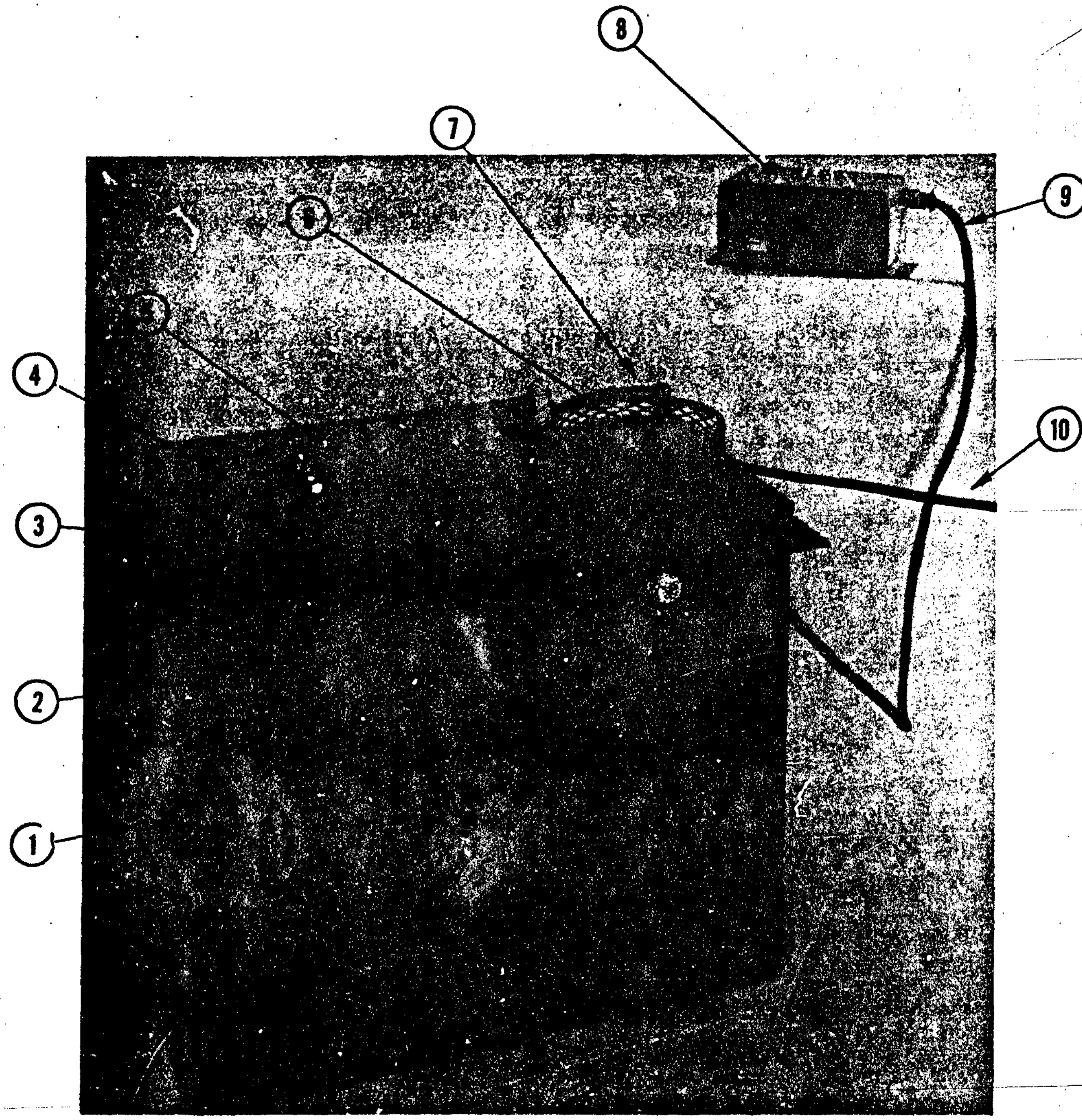
E Delete paragraph II.A.2.b - relative to the Production Study Report.

Supplemental Agreement and/or Modification No. 8 extended the funding period through 30 November 1965 to complete the contractual effort cited in this report.

The Filter Unit is defined as a self-contained air-purifying unit consisting of a mechanical dust separator, airflow control valve, particulate filter, gas (charcoal) filter, deep-fording valve, fan, and control panel for installation in the MBT. In operation, the Filter Unit continuously provides purified air through the proposed MBT Environmental Control Unit (ECU) and/or directly to the crew compartment, to maintain a satisfactory level of protective pressurization in the crew compartment when the vehicle hatches are closed.

The Feasibility Phase of this contract, covering approximately 15 months, included feasibility and design studies, and fabrication and evaluation testing of working models.

The Development Program Phase of the contract, after partial termination of the contractual effort, included nine months of development effort, including updating Class II drawings to Class I status, preparation of purchase descriptions, fabrication and test of two preproduction prototype E49 Filter Units, fabrication of 12 E49 Filter Units from Class I drawings and purchase descriptions, and preparation of reliability and acceptance test methods. Figure 1 illustrates the Filter Units developed during this phase.



1. Air Outlet
2. Housing
3. Mounting Flange
4. Filter Access Cover
5. Lifting Eye
6. Bulkhead Connector
7. Precleaner Lifting Handle
8. Control Panel
9. Control Cable
10. Power Cable

Figure 1. Gas-Particulate Filter Unit, Tank, EMD, 400 CFM, E49

II BACKGROUND

A PROTECTION FROM CB AGENTS

Field protection of armed forces personnel from chemical and biological (CB) agents is an important facet of United States military capability. The need for protection from chemical agents was graphically illustrated during World War I and, as a defensive measure, has been unquestionably important ever since.

Protection against CB agents includes removal of both particulate and gaseous forms of toxic matter dispersed in air. Dispersions of particulate material, whether solid or liquid, are often referred to as aerosols. Bacteriological agents may exist dispersed in air as solid, dry particles or incased in liquid droplets. Particulate filters protect against aerosols and remove nearly all particulate matter from the air stream.

Chemical agents may be present in either or both the liquid or gas phases. Since chemical agents existing in the gas phase will pass through a particulate filter, a sorbant type filter is required for protection. The established material for this use is granular ASC Whetlerite, an activated charcoal. Though some chemical agents, such as persistent gases, are dispersed as aerosols and are collected on the particulate filter, a certain amount will still off-gas or vaporize causing harm to personnel if not removed by a gas filter. Thus, CB protection requires a device to separate or collect particles as well as a sorbant to remove gases.

CB protective units offer limited radiological protection by collecting radioactively charged particles in the particulate filter, thus preventing ingestion by those protected. Protection against radiation dangers such as gamma rays requires extensive shielding. Shielding against radiation is not within the scope of this contract.

B POSITIVE-PRESSURE COLLECTIVE PROTECTION CONCEPT

Protection against bacteriological and chemical warfare agents was originally provided on an individual basis by face mask and canister. Further development extended protection to two to five persons, each using an individual face mask, but supplemented with a central filtration system and interconnecting hoses. This offered protection collectively to the group. The positive-pressure collective protection concept extends chemical and bacteriological protection to entire enclosures.

As long as the possibility of biological, chemical and radiological warfare exists, there will be a requirement for protected enclosures where men can live and work without special clothing and masks. The most economical method is to pressurize the enclosure with clean or purified air. For enclosures with exterior walls protected from the wind, an internal positive

pressure of 0.5 in. water is adequate to prevent the ingress of contaminated air. For enclosures, such as vehicles, with exterior walls which are not protected from the wind, an internal pressure significantly higher than the wind and/or vehicle speed velocity must be maintained to prevent the ingress of contaminants. The quantity of purified air required also depends on the enclosure leakage and operation (firing mode) of the vehicle's main armament. The allowable leakage must be small enough to allow using a collective protection unit of reasonable size.

C VEHICULAR APPLICATION

This project is concerned with CB protection for an armored mobile vehicle, the Main Battle Tank. The results obtained here are also directly applicable to other vehicles with small crew compartment leakage.

Airlocks or other forms of protective entrance are normally required on stationary installations such as shelters or tents. The positive-pressure collective protection concept applied to vehicles assumes that the vehicle is capable of operating in a hatches-closed condition while in the contaminated area, but retains the capability of travelling out of the contaminated area before the hatches are opened. If this cannot be done, and the interior becomes contaminated, individual face masks must be used until the internal atmosphere can be scavenged with purified air to reduce contaminant concentration to a safe level.

Operation in a sealed condition also provides a more livable atmosphere for the crew. For example, the MBT as proposed, contains an air conditioning unit to regulate crew compartment temperature and humidity. Using the collective protection unit, even when toxic agents are not present, also removes other odors and particulate matter not necessarily toxic. The positive-pressure collective protection concept not only protects the life of the crew during chemical or biological attack, but increases crew efficiency at all times by conditioning their operating environment.

Providing CB protection to vehicle crew compartments involves four basic problems which are not significant in stationary installations. These are dust concentration, shock and vibration, power, and size or cubage.

Dust concentration surrounding vehicles in general, and tracked vehicles in particular, can be extremely high. Since particulate filters are so efficient in collecting particulate material, dust capacity (ability to collect a quantity of material without causing excessive air resistance or pressure drop) is limited. Also, the required air flow in compartment pressurization systems is higher than that needed only for crew member respiration. The major portion

of the airflow in positive-pressure collective protection applications is used to offset leakage and maintain crew compartment pressure. Thus, even with a mechanical dust separator to remove the majority of dust, dust capacity of the particulate filter is a critical design consideration.

Shock and vibration have deleterious effects on most commercially designed particulate and gas filters. Particulate filters are subject to media fractures; while settling by redistribution and granule disintegration occurs in gas filters. Filters for vehicular use must be designed to withstand the rigors of combat use without loss in performance caused by structural breakdown.

Both size and power are also of primary importance in vehicular applications. The requirement for minimum size dictates different design approaches than would be used for stationary collective protection. Generally, size reduction is inversely proportional to cost. The same relationship holds for power. Other characteristics such as noise and weight likewise are important, but to a lesser degree.

Collective protection has previously been developed for vehicular application on the Mauler Weapons Pod. Stationary installations of a similar nature exist for the Hawk, Nike Hercules, Missile Monitor, and like systems. Positive-pressure collective protection for the Main Battle Tank is an additional step in providing this capability to military armored combat vehicles.

III DESIGN AND PERFORMANCE REQUIREMENTS

The design and performance requirements of the Gas-Particulate Filter Unit as specified in the contractual work were based on proposed MBT Quality Material Requirements (QMR) and US Army-Tank Automotive Center's (ATAC) predictions of vehicle leakage (200 cfm normal, 400 cfm in the firing mode), stowage space for the Filter Unit, and MBT Military Characteristics.

A DESIGN REQUIREMENTS

1 Designed for installation in the MBT during tank production.

2 A complete self-contained unit, mounted in an enclosed space, and capable of marriage with an Environmental Control Unit (ECU) supplying conditioned air to the crew compartment. The allotted space for the Filter Unit shall be approximately 26 in. high x 23 in. long x 14.5 in. wide, exclusive of that volume required for the fan assembly.

3 Capable of successful operation under the following vehicle operating conditions:

a. Under ambient temperature extremes of +125°F to -65°F, and after extended periods of storage at ambient temperature extremes of +155°F to -65°F.

b. On 60 percent longitudinal and transverse slopes.

c. Under all vibrational, shock, environmental, and field use tests required of the MBT without major change in its overall protection efficiency. Appendix A details these requirements.

d. During vehicle operation in deep-fording, dusty, and contaminated areas for a minimum of 24 hours continuous operation.

e. Under battle conditions, capable of pressurizing and maintaining the crew compartment of the vehicle to a minimum of 1.0 in. water gage positive pressure.

4 Provided with means to seal intake ports to protect the filters during deep fording. There will be no air intake to the Filter Unit during deep fording. Deep fording is considered as 24 feet.

5 Design providing: design simplicity allowing ease of installation, maintenance and repair; system compactness for minimum stowage space; lightweight components compatible with structural requirements; minimum noise and vibration; and freedom from acoustically objectionable frequencies.

B OPERATIONAL REQUIREMENTS

The following subsystems or components are specified for inclusion in the Filter Unit to obtain the required performance:

1 Fan assembly capable of providing 400 cfm of air through the purification system.

2 Mechanical dust separator for removing a minimum of 93.0 percent of all dust particles from a dust cloud containing 0.025 gm/cu ft AC Coarse Test Dust at an air flow of 400 cfm. Separated dust shall be continuously discharged overboard.

3 Particulate filter containing aerosol filter media capable of removing at least 99.97 percent of smoke and aerosols. Filter medium shall be in accordance with MIL-F-51079[1] dated 6 April 1962. Particulate filters shall be fabricated of material set forth in MIL-F-51068[2], dated 6 April 1962, and Supplement No. 1, dated 15 January 1963, wherever practicable.

4 Gas filter containing material capable of providing complete protection against all toxic gaseous CW agents. Material shall be ASC Whetlerite in accordance with MIL-C-13724A[3], dated 1960.

5 Required mechanical controls and/or electrical controls and indicators consisting of the following:

a. Deep-fording with indicator light.

b. Controllable air flow from 135 to 400 cfm.

c. Fan assembly with indicator light.

d. Crew compartment pressure with indicator light.

e. Indicator light for particulate filter replacement.

f. Control Panel.

C SUPPLEMENTAL REQUIREMENTS

In addition to the above requirements, contract Modification No. 5, dated 18 January 1965, gave direction for conducting a feasibility study of state-of-the-art methods for providing blast protection for the Filter Unit. This authorization covered an evaluation study of the hazards of blast damage to the filters and other components of the Filter Unit. A study of potential approaches for providing blast protection and a design study to determine the feasibility of providing a combination antiblast closure/deep-fording valve. The closure device would meet the design and operational requirements of the Filter Unit and components.

Additional Project Officer's technical modifications to Contract requirements include:

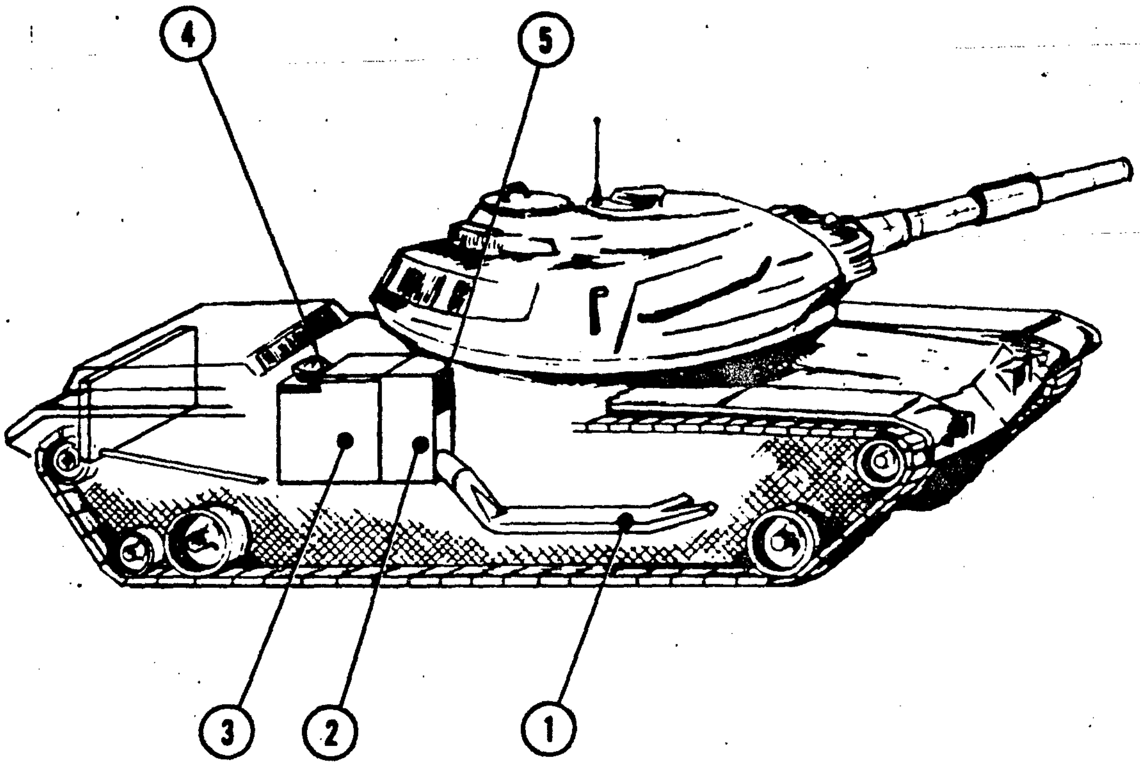
Changing the Filter Unit air outlet size to 8.0 x 13.25 inches to mate with the inlet of the proposed environmental control unit.

Changing the precleaner efficiency requirement from 93.0 percent to 92.0 percent on AC Coarse Test Dust fed with an AFI dust feeder. This was changed since it wa determined that dust removal efficiency is affected by the configuration of the airflow control valve and that different efficiencies can be achieved through various methods of testing.

D INTEGRATION TO MAIN BATTLE TANK

A prime design requirement of this contract is that the Filter Unit be designed for installation in the Main Battle Tank (MBT) during production. The Filter Unit is designed to mount within the MBT engine compartment, in proximity to the proposed ECU. The Filter Unit/ECU combination is referred to as the Environmental Control System (ECS).

The space originally allocated for the Filter Unit measured 23 in. long by 14.5 in. wide by 26 in high, not including the fan assembly. Through design analysis, summarized in the Design Study Report[4], it was concluded that inclusion of all necessary Filter Unit components, ·cluding fan, within the allocated volume was not possible within the present state-of-the-c . Therefore, the allocated space was increased in length to 30 in. Thus, the current Filter Unit envelope measures 30 in. long by 14.5 in. wide by 26 in. high and includes the fan assembly. The proposed space is located in the right side of the MBT engine compartment beginning approximately 40 in. aft of the tank center line. Figure 2 shows the space allocation for ECU components in relation to the entire vehicle. The Filter Unit is mounted aft of the ECU. The Filter Unit discharges purified air on the forward 14.5 in. side to the ECU through a rectangular opening. Air for the Filter Unit is drawn through the vehicle's ballistically designed louvers which mount over the Filter Unit and into an annular opening aft and at the top of the Filter Unit. The louvers above the Filter Unit are hinged in sections for access to the engine compartment and unit. Access for installation and removal of the Filter Unit is made by swinging these louvers upward. A power source of 27.5 ±0.5 vdc was selected since it is the only available power source presently specified for the MBT. Other sources may become available as MBT development progresses. This uncertainty eliminated potential use of hydraulically or pneumatically operated components within the Filter Unit such as the deep-fording valve and airflow control valve. Also, since the Filter Unit must be removed to service certain ECU components, it must be completely and easily removable.



1. Distribution Duct
2. Environmental Control Unit
3. Filter Unit
4. Air Inlet
5. Return Air

Figure 2. Environmental Control System Within Main Battle Tank.

The design status of the MBT vehicle, or test rig, by ATAC also necessitated assumptions regarding potential integration into the MBTas it is finally conceived and built. For example, the location and configuration of the mounting flange was chosen to be reasonable from both a possible MBT installation viewpoint and a test fixture mounting standpoint. The proposed method of Filter Unit mounting involves hanging the unit from a flange surrounding the Filter Unit housing near the top. This flange mates with the proposed bulkhead extending from the crew compartment. In effect, then, the Filter Unit and ECU mount into a sealed extension of the crew compartment. The only portion of the Filter Unit which must withstand the 24 ft water fording pressure is the top, above the mounting flange. Though the Filter Unit has been designed specifically for the Main Battle Tank, it does have application for other vehicles.

IV FILTER UNIT DESIGN CONCEPTS

A DESIGN STUDY

The fan, particulate filter, and gas filter are basic to the Filter Unit in order to provide purified air to the crew compartment of the MBT. Other elements, such as the dust separator, dust filter, deep-fording valve, airflow control valve, and indicating and warning devices are secondary to such a system. Of the three basic elements, airflow could be supplied by engine accessories such as a supercharger. However, this approach was not considered feasible since the MBT engine had not been selected. Since there are no vehicular counterparts to either the particulate or gas filter, a particulate filter and gas filter, in addition to the fan are required in any feasible concept.

Eight different concepts evolved from this analysis. Each of these contained the three basic elements, but varied in their location and sequence in relation to the secondary elements.

Concept A: Deep-fording valve, fan assembly, dust separator, airflow control valve, dust filter, particulate filter, and gas filter in that order.

Concept B: Same components as Concept A, but with the fan assembly between the dust separator and airflow control valve.

Concept C: Used engine air cleaner for mechanical dust separation and thus required only a fan assembly, airflow control valve, dust filter, particulate filter, and gas filter.

Concept D: Fender-mounted dust separator with deep-fording valve, with the fan assembly, airflow control valve, dust filter, particulate filter, and gas filter beneath the louvered grill.

Concept E: Same components as Concept A except eliminated the dust filter.

Concept F: Same components as Concept A, but eliminated the dust separator.

Concept G: Used the engine supercharger to eliminate the fan assembly, dust separator, and dust filter.

Concept H: Used the deep-fording valve, dust separator, and dust filter on the vehicle fender ducted to the Filter Unit, which contains a fan assembly, airflow control valve, particulate filter, and gas filter.

Concept G was eliminated from consideration since the Filter Unit could only operate when the engine was under load. Each of the seven remaining concepts involved 11 or more subsystems, devices, and/or elements per concept and an unknown number of arrangements and shapes of these components as well as an unknown number of designs to accomplish the functions of each subsystem device and/or element.

In order to reduce the variables to a manageable and workable level, each subsystem device and element was analyzed to reduce the number of alternatives to a minimum. Concurrent with this investigation, potential shapes and arrangements were studied to determine the optimum utilization of space within the Filter Unit. To facilitate this work, the design parameters of the various components were expressed in a mathematical model and the various trade-offs were computer analyzed.

The remaining potential configurations were analyzed from the standpoint of whether the components would be internal or external to the Filter Unit. The final step evaluated these arrangements in relation to contract requirements.

In order to objectively evaluate the 22 alternate arrangements that survived the above screening, a numeric rating system was used to evaluate each configuration against contract requirements. Seven basic rating features were used and weighted values were assigned to each feature as follows:

Rating Feature	Value, points
Pressure Drop	25
Cubage	25
Fan Assembly Life	10
Maintainability	10
Reliability	10
Product Cost	10
Other	10
Total	100 points

As a result of this analysis, three designs were proposed for Government selection. Each included a separate dust filter to act as a prefilter for the particulate filter. Design No. 1 contained the dust, particulate, and gas filters within a 23 in. long x 26 in. high x 14.5 in. wide (5.0 cu ft) envelope. The fording valve, fan assembly, dust separator, and flow control valve were contained in a module attached to this envelope.

Design No. 2 had an externally mounted fording valve, dust separator, and dust filter with the remaining components within the 5 cu ft envelope in the engine compartment. Design No. 3 used the engine air cleaner to preclude the necessity of dust separator tubes within the Filter Unit.

It was decided at a technical meeting with representatives of U.S. Chemical Research and Development Laboratories, U.S. Army Tank Automotive Center and U.S. Engineering Research and Development Laboratories that: (1) the Filter Unit must be capable of operation independent of other vehicle components; (2) the Filter Unit must be completely within the engine compartment as a self-contained unit; and (3) a dust filter should not be used.

It was also proposed at this meeting that the Filter Unit mount with a flange located near the top of the unit, with the major portion of the unit suspended within and protected by an external bulkhead. This requirement dictated the direction of the air flow which must enter the 14.5 in. x 30 in. side (top) and exit on the 14.5 in. x 26 in. side (end). The airflow pattern, in turn, dictated the general shape of the three major components: the particulate filter, gas filter and the fan assembly. Although this did not exactly match designs proposed in the Design Study Report[4], the basic design information allowed ready adaptation to the new configuration requirements.

B DESIGN APPROACH

1 General

The rectangular configuration specified for the Filter Unit dictated the shape of various components, with the exception of the fan assembly. That is, the best volumetric use of the rectangular space required components of rectangular cross-section also. The fan assembly, being a rotating mechanism, has a cylindrical shape. By using the space adjacent to the fan assembly for various control components, optimum use of this space was also possible.

Actual dimensions of the major components were somewhat dictated by space configurations, airflow pattern, and individual component performance characteristics. For example, the height and width dimensions of the gas and particulate filters were based primarily upon the necessary airflow pattern. This airflow pattern required that air enter on the top, the 14.5 in. x 30 in. side, and exit on the upper half of the downstream end, the 14.5 in. x 26 in. side. With this air flow, the most logical placement of both filters was against the 14.5 in. x 26 in. end. With the latter cross-sectional area determined, the lengths

could then be varied to give the required performance. The best balance between volume allotted to the fan assembly, particulate filter, and gas filter was approached from both mathematical and practical design standpoints.

The mathematical approach used performance equations representing the Filter Unit. Performance data for each of the major components were reduced to equations which could be manipulated mathematically. Basic design information was supplied partially by the Government and partially by the contractor.

The original Filter Unit mathematical model, Figure 3, has been updated. Cubage equations have been eliminated from this updated mathematical model because of the many limitations placed on the original equations. The model is divided into four main sections: dust separator, particulate filter, gas filter, and fan assembly. Any change made to any specific component affects all other components. The equations shown on this model are the basic equations used for performance design of the filter unit. The fan equations are based on empirical data for the fan assembly used in the optimum development model filter units.

2 Deep-Fording Valve

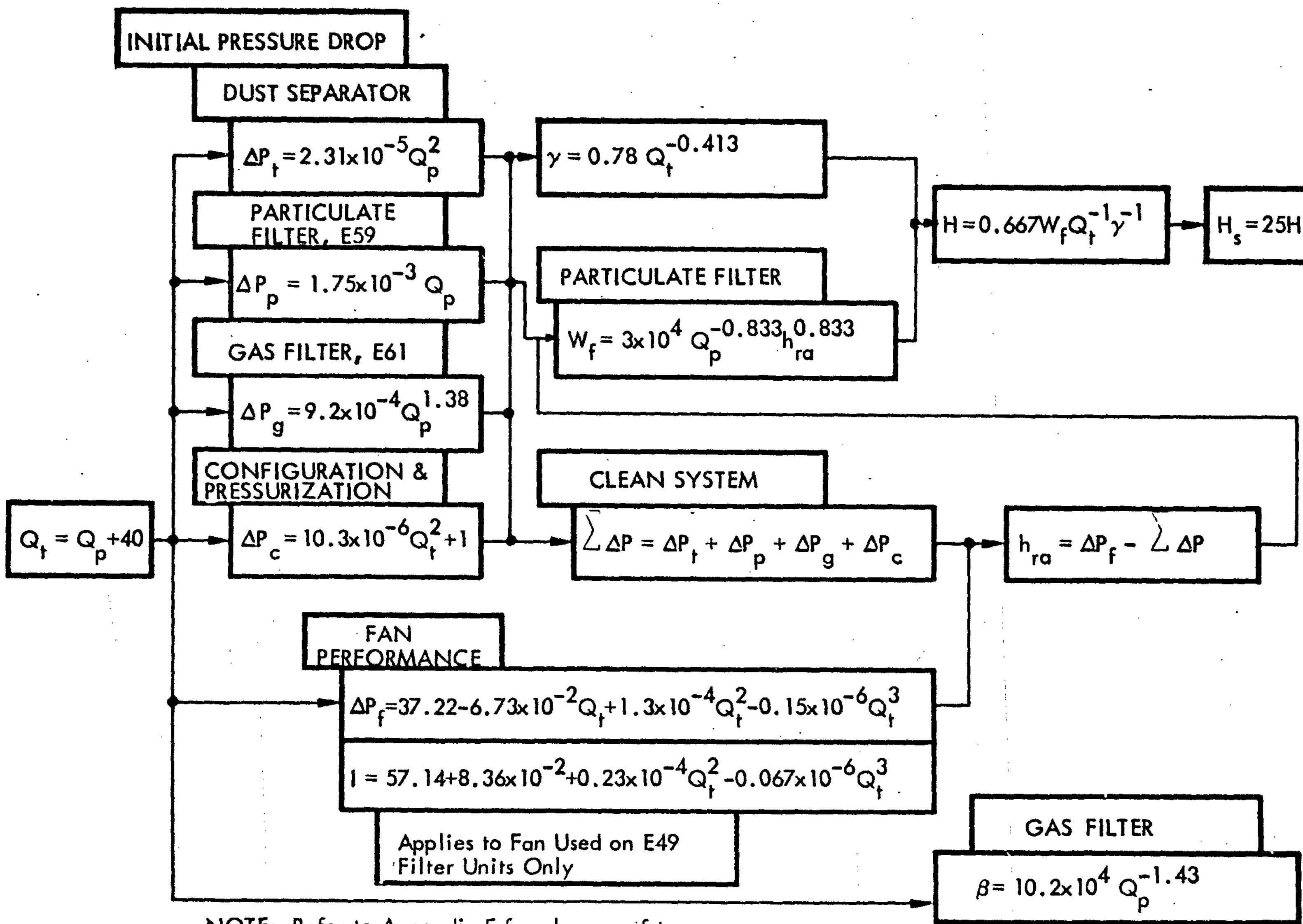
A deep-fording valve is necessary to protect the Filter Unit and the crew compartment from entry of water during fording operations of the MBT. The design depth for fording is 24 feet of water. The air intake, dust exhaust outlet, and atmospheric reference pressure tap are openings that must be sealed during deep-fording.

These openings must be sealed by remote control from the crew compartment. An indication must also appear in the crew compartment when the ports are properly sealed. The valve must operate under conditions of dust, water, ice, and other foreign material.

A large number of valve types were considered for this component. These included butterfly, gate, slider, plug, ball, pinch, expandable plug, rotating sleeve, coned plug, piston, hinged cover, and poppet cover types.

Many potential actuating devices for the deep-fording valve were also studied. These included electric motors, solenoids, hydraulic and pneumatic cylinders, flexible shafts, mechanical linkages, pressurized cartridges and floats.

The two secondary outlets of the Filter Unit, the dust scavenging outlet and atmospheric pressure tap, were considered for separate sealing means, using a number of approaches including those above. Two of these approaches considered involved use of a snorkel, similar to that used on scuba diving equipment, or a solenoid actuated ball cock valve.



NOTE: Refer to Appendix F for glossary of terms.

Figure 3. Filter Unit Design Mathematical Model.

The Filter Unit was designed so that all three openings are in close proximity, allowing all openings to be sealed by a single device.

The device chosen for the fording valve is basically a poppet cover which lifts from its seat, forming an annular inlet opening. A poppet cover valve requires linear actuation. Solenoids offer a simple solution, but have the disadvantages of short stroke, small force, and require continuous power to hold in one position. The actuation method chosen as most applicable was a 27.5 vdc reversible electric motor. The motor power is transferred from rotary motion to linear motion through a simple gear train and drive screw arrangement.

Choice of a poppet cover driven by an electric motor was based on factors of allowable space, function, and reliability. The space available for the fording valve function was above or upstream of the fan assembly. As such, it was necessary to use a device which did not unduly disturb the airflow into the fan assembly, since flow disturbances cause less efficient fan operation.

3 Fan Assembly

The contract requires a fan assembly capable of supplying 400 cfm purified air to the ECU. Since the mechanical dust separators recommended for the Filter Unit require 10 percent of primary airflow or 40 cfm for exhausting dust, the fan must produce 440 cfm. This assumes that no separate dust exhaust blower is used.

Fan output pressure and power requirements relate directly to filter component sizes. For a given air capacity, fan output pressure and power increase as the filtration train size decreases. Fan output pressure also depends upon impeller tip speed. Factors such as reliability of bearings and brushes, cost, and noise indicated 12,000 rpm maximum fan speed.

The fan assembly must supply airflow from 400 cfm maximum to 135 cfm minimum, depending on crew compartment leakage. Thus, the airflow vs pressure characteristics are of greater importance here than in a constant flow application. The characteristic pressure vs airflow curve should slope not less than 1 inch of water per 75 cfm between 440 cfm and 150 cfm with no significant saddle at low flow/high pressure conditions.

Fan assembly requirements restricted the choice to centrifugal, vane axial or mixed flow types. Size, weight, and power requirements negated use of other types such as positive displacement blowers. Centrifugal fans normally exhaust air 90 degrees from the original airflow direction. The most feasible Filter Unit designs required a straight-through or axial flow pattern. This factor, in addtion to the large volume of air required, eliminated centrifugal type fans.

Axial flow fans of the vane axial type have the desired flow pattern, but require multiple impellers and motors to meet the pressure requirements. Staging of impellers again creates a size problem.

Mixed flow or tubular centrifugal fans combine van axial and centrifugal features. Air enters the fan through impeller vanes which begin axially but gradually become radial. Thus, the axial and radial airflow components are mixed. This type offers high capacity and pressure for a given envelope volume. Such fans also offer advantages of compact size and sturdy construction.

Five different types of power source were considered for powering the fan; mechanical, manual, hydraulic, pneumatic, and electrical. A mechanical power source requires a power take-off from the vehicle engine. This had the obvious disadvantage of requiring a specially designed power take-off and of incompatibility with different vehicles. A manual system requires a crank or other device operated by a crew member, which is not feasible in this power range. Hydraulic and pneumatic power were possible sources if there was sufficient power of that type in the vehicle. Electric dc motors appeared the most practical. They are relatively compact and operate reliably. The major weaknesses in electric motors are bearing and brush life. The life of each is directly related to motor speed.

Brushless motors eliminate the brush wear problem of dc motors, however, at the present stage of development, these motors only exist in small power ranges. Thus, brushless motors for the Filter Unit were considered beyond the state-of-the-art.

A mixed flow type fan, powered by a series-wound dc motor, was selected for use because of its size and capability of integration into the Filter Unit. Had current draw and cost been more critical, size less critical, or if the required pressure output been increased, a centrifugal type would have been recommended.

No off-the-shelf blowers were available for this application. Therefore, a fan assembly specifically designed for filter unit use was developed under subcontract.

4 Mechanical Dust Separator

The mechanical dust separator reduces the concentration of dust reaching the particulate filter. This contract requires the use of a mechanical dust separator capable of removing a minimum of 93 percent of all dust particles from a dust cloud containing 0.025 gm/cu ft of AC Coarse Test Dust. It also requires that separated dust be continuously discharged from the Filter Unit.

Three types of mechanical dust separator tubes, previously developed by the contractor, were considered for this requirement. Two of these tubes were axial inlet, reverse-flow cyclone tubes while the third type was an axial inlet, straight-through centrifugal separator tube. For purposes of this report they have been designated as follows:

Design No. 1: reverse-flow cyclone tube with 45° vane.
Design No. 2: reverse-flow cyclone tube with 22 1/2° vane.
Design No. 3: straight-through centrifugal separator tube.

Each of these is illustrated in Figure 4.

All the separator tubes evaluated are commercially-available production items used in civilian and military applications. The Design No. 1 tube was developed for heavy-duty engine air cleaners of high airflow. Design No. 2 tubes are used on heavy-duty engine air cleaners of lower air flow. The Design No. 3 tube was developed primarily for protection of gas turbines and other high airflow applications where compactness is essential.

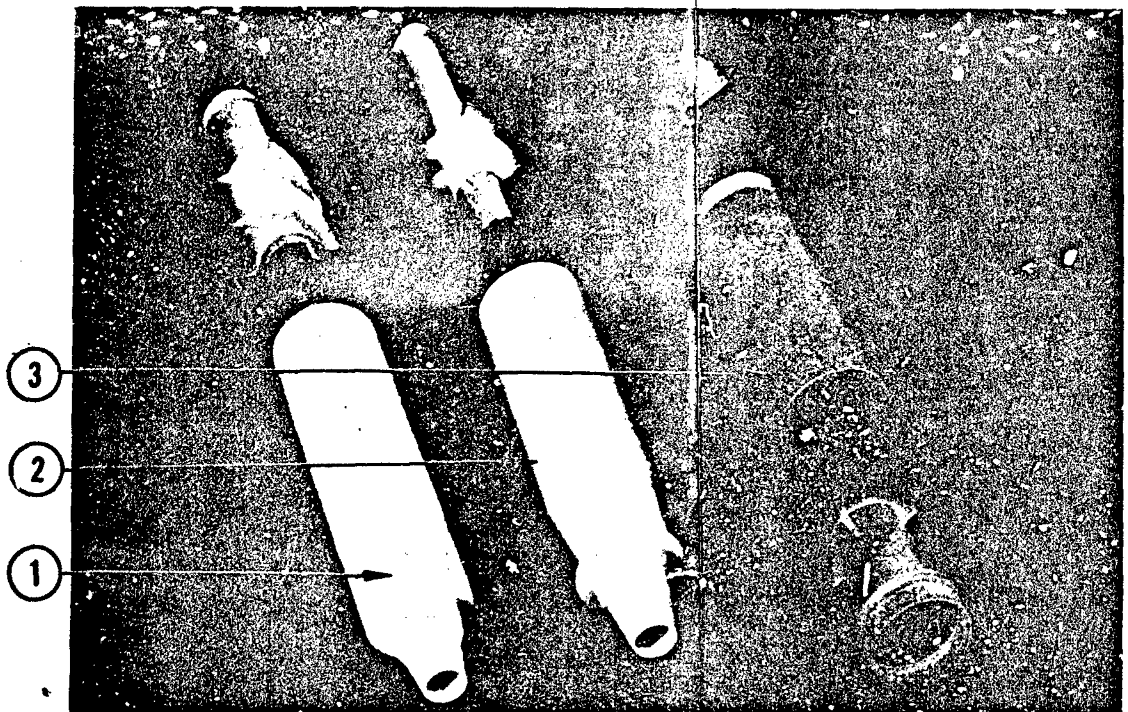
Scavenging flow is required for the Design No. 3 tube, but is optional with the reverse-flow cyclone tubes. With the requirement for continuously discharging the dust overboard, scavenging flow was considered necessary for all separator tubes. Scavenging flow is that additional air flow used to exhaust the separated dust. Primary airflow is that flow passing through the filters and to the crew compartment. The summation of primary and scavenging flow is defined as total flow.

The amount of scavenging flow required is about 10 percent of the primary flow in each of these tubes. At a constant pressure drop across the separator tubes of 4 in. w.g., the following performance could be expected:

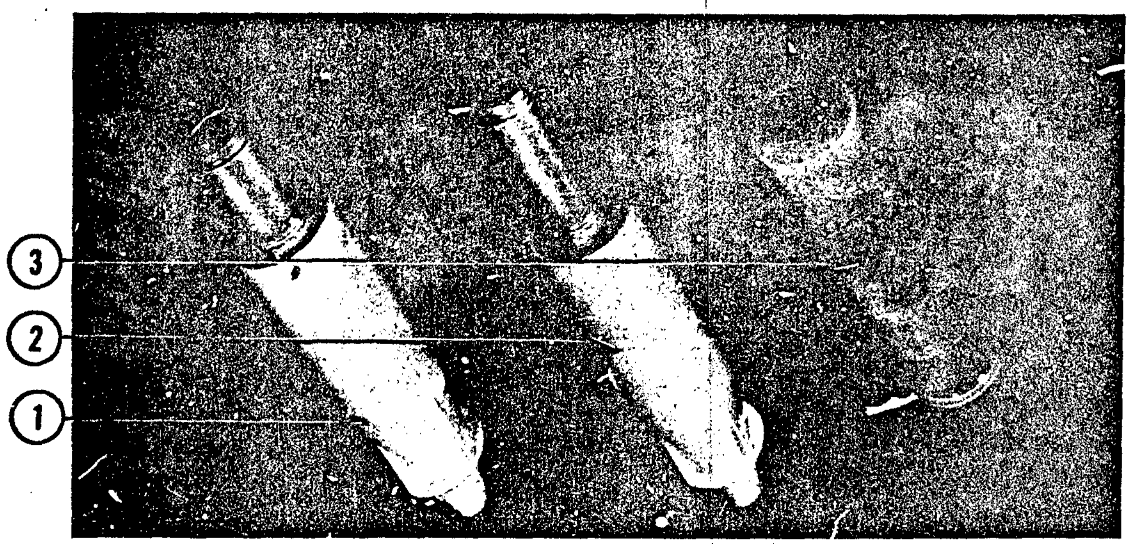
Tube Design No.	Primary Air Flow, cfm	Efficiency, percent
1	11.4	96
2	7.8	98
3	30.0	93

These efficiencies are based on AC Coarse Test Dust.

Each of the mechanical dust separator tubes is approximately the same size; 1.5 in. diameter by 6 in. long. The different airflow pattern between the reverse-flow types of Design No. 1 and 2 and the straight-through flow of Design No. 3 dictates a significantly different separator configuration. Work preceding the Design Study Report[4] analyzed the pos-



EXPLODED VIEW



ASSEMBLED VIEW

1. Reverse-Flow Cyclone Tube With 45° Vane
2. Reverse-Flow Cyclone Tube With 22.5° Vane
3. Straight-Through Centrifugal Separator Tube

Figure 4. Mechanical Dust Separator Tubes.

sibilities for using each design. This analysis was based upon tube efficiency at rated and reduced air flows, effect of separator tube location in relation to the fan assembly, and volume requirements.

Based on the balance of tube efficiency and required volume, it became evident that only Design No. 3 was feasible for the Filter Unit if mounted totally within the engine compartment. It was, however, a conclusion of the Design Study that if an external dust separator (fender mounted, for example) could be used, the Design No. 2 separator tube would show greater advantage. In this case the higher efficiency would have been more important than space consideration. Since the Filter Unit had to fit within the volume allotted, the Design No. 3 mechanical separator tube was chosen.

Approximately 40 cfm or 10 percent of the 400 cfm primary flow is exhausted from the tube section to carry off separated dust. This scavenging airflow could have been supplied by two methods. One was to draw air from the dust collection chamber by means of a separate blower or exhaust ejector. Ejectors were rejected because of their variable airflow with change in engine speed. A separate blower was also undesirable because of reliability, cost, size and space requirements. An alternate method – the method used in the optimum units – uses a blow-down technique. The blow-down technique requires that the mechanical dust separator assembly be located downstream of the fan assembly and preferably upstream of the airflow control valve. The passage for the scavenging air is sized so that when the airflow control valve is in the full open position, allowing 400 cfm to the crew compartment, 10 percent or 40 cfm passes through the dust chamber to exhaust the collected dust. When the airflow valve is in a partially closed position, the increased air resistance of the valve reduces fan air output. The increase in airflow through the scavenging system, however, is negligible. Scavenging flow remains approximately 40 cfm regardless of the airflow control valve position. Since the primary flow, or the flow to the crew compartment, is less than 400 cfm in these conditions, the airflow per separator tube is also less. Thus, with less primary flow per tube and the same scavenging flow, the percentage of scavenging flow increases as the airflow control valve closes. This increasing percentage of scavenging flow tends to offset the characteristic decline in separator tube efficiency at lower air flows.

5 Airflow Control Valve

The purified air output of the Filter Unit must be controllable between 135 and 400 cfm. This airflow is regulated to maintain crew compartment pressurization at 1.0 in. of water minimum. Maintaining only the airflow needed for crew compartment pressurization has the advantage of decreasing flow through the particulate and gas filters. This increases

filter service life and decreases the heating or cooling load on the ECU.

Airflow can be controlled by two basic methods: motor speed variation and mechanical flow restriction. Controlling motor speed eliminates the extra mechanical flow control device and uses only enough power to supply the required air flow. The most favorable method of controlling motor speed utilizes a rheostat controlled shunt-wound dc motor. However, shunt-wound motors having the necessary speed and size requirements were not available. A survey of motor manufacturers indicated that such motors running at 10,000 rpm or higher are beyond the current state-of-the-art. Series-wound dc motors could also be used. However, the rheostat required to dissipate the required load would offset any space savings. Therefore, it was decided that flow must be controlled mechanically.

In order to best use the blow-down method of scavenging the separated dust, the airflow control valve should be downstream of the dust separator. Available space was the primary consideration in selecting the airflow control valve design.

Many types of mechanical flow restriction devices were reviewed in selecting the design for the Filter Unit. These included butterfly, expanding boot, iris, rotating plate, and sliding type valves. Actuation for these controls could be performed by electric motors or cylinders for either hydraulic or pneumatic operation. A sliding plate-type valve, actuated with a reversible dc motor, was chosen for the airflow control function after analysis of space, reliability, and maintainability requirements.

Sliding plate-type valves considered for the Filter Unit included both rotating segment and matched plate designs. The rotating segment type consists of a fixed shallow cup with a portion of the side removed. A rotating member, in the form of a segment of a cup, fits within this outer cup and rotates so that the opening can be closed or opened, to regulate the flow. This design, did not allow even distribution of backpressure on the downstream end of the dust separator tubes. Therefore a matched plate approach was selected for use.

The matched plate approach requires a pair of plates; one stationary and the other capable of rotation in relation to the fixed plate. Each plate contains openings designed so that when the plates are in one position the openings match each other. If one plate is rotated, the openings close.

Various configurations were fabricated and tested. Analysis of the potential configurations showed that if the openings were few and large, the air was not sufficiently distributed. On the other hand, with many small openings, a very small amount of plate ro-

tation changed the flow from maximum to minimum, creating a very sensitive control. The best balance was achieved with the spiral configuration.

6 Dust Filter

Filtration systems for both stationary and vehicular applications commonly use a dust filter or prefilter upstream of the particulate filter. A prefilter is normally an inexpensive item used primarily to extend the life of the more expensive particulate filter. Also, a prefilter can be reusable or cleanable.

In the feasibility study, the use of a prefilter was considered, to extend the life of the particulate filter. Inclusion of a dust filter involves additional cubage, cost, and logistics problems.

There are two approaches to prefiltering. The first uses a loose fibrous mat of sufficient thickness to give the desired dust loading and collection efficiency. This type of filter commonly is composed of thin, low efficiency layers of fibers with considerable space around each fiber. Pressure drop is very low, but efficiency is likewise quite low.

The second approach uses a tight, highly efficient fibrous mat which retains the dust on the surface of the mat. This type filter depends on the dust cake for its performance characteristics and on extended surface area, normally provided by pleating, to provide the required dust loading capacity. The dust filter media selected for study for the Filter Unit application was a compromise between the above extremes. Its action depended primarily upon the extended surface of a thin pleated media whose structure permitted some penetration for increased dust loading but collected the bulk of the dust on the surface of the media.

In order to establish the design requirements of the filter material and the filter configuration, a series of performance tests were run on two types of prefilter dust media and one type of particulate media per MIL-F-51079[1]. The basic question was whether the cost of frequent replacement of the particulate filter would be offset by the design complications of the dust filter and the additional logistics problems. It was decided by the Government that more frequent particulate filter replacement was not as critical. Therefore, the separate dust prefilter was eliminated from the design.

7 Particulate Filter

The particulate filter removes essentially all particulate matter dispersed in the air stream before reaching the gas filter and crew compartment. The particulate filter must have an efficiency greater than 99.97 percent when tested against a 0.3 μ DOP

(dioctylphthalate) aerosol. The DOP aerosol test is a standard means of determining the efficiency of a filter design to remove microscopic particles from the air. DOP is an oily liquid with a very low vapor pressure. To determine the efficiency of a particulate filter, the DOP is dispersed in air as droplets. The 0.3 μ diameter aerosol used for specification testing is an extremely homogeneous aerosol produced by heating the DOP, diluting the vapor with air, and cooling the mixture under carefully controlled conditions. Accurate measurements of aerosol particle concentration are made in a light-scattering chamber provided with a sensitive photoelectric detector. The penetrometer (detector) is calibrated against a full aerosol concentration (100 percent) and against absolutely clean air (zero percent). Penetration through the filter can then be read directly in percent, with a 0.001 percent sensitivity. In general, the aerosols encountered under field conditions (biological agents, radioactive dust particles, low-vapor-pressure chemical warfare agents, etc.) will be larger than 0.3 μ and the percent penetration will be lower than the specification value.

The filter media specified to meet this requirement is MIL-F-51079[1] glass-fibered filter media. This media has the disadvantage of being extremely fragile and subject to damage from shock and vibration. Also, the high efficiency of the media allows only limited dust loading before pressure drop becomes excessive.

Pressure drop is the major parameter controlling the Filter Unit design. This is apparent from the mathematical model in Figure 3. It is not only the initial or clean pressure drop which must be considered, but the final pressure drop after the Filter Unit has operated in a dust-contaminated atmosphere. The pressure drop through a clean particulate filter is linear with airflow, but the pressure rise due to the dust loading is a function of the area to the 2.2 power (based on empirical data). Increasing the effective area of the particulate filter reduces the pressure rise due to dust loading and thereby reduces overall system pressure drop.

The protective efficiency of the particulate filter is enhanced by increasing the area. The protective efficiency requirement for the particulate filter can be met with a filter operating at a velocity of as high as 10 ft/min. However, a velocity through the media of 5 ft/min or less is desirable to keep the overall power requirement of the Filter Unit to a minimum and to increase its dust loading capacity.

Another specification relative to particulate filters for the Filter Unit stated that construction should follow MIL-F-51068[2] dated 6 April 1962 and Supplement No. 1 dated 15 January 1963 whenever practicable. These documents specify use of fluted or corrugated metal spacers to separate pleats, type of endseal material, and frame construction.

Particulate filter design parameters from the performance standpoint have been established by long military and commercial use. Typical guide lines call for pleat depth limited to approximately 6 in. and pleat spacing not to exceed 4.5 pleat/in. Each of these guide lines are related to pressure losses in pleat entrances. The volume allotted to the particulate filter was nominally 6 in. deep with a 14 in. x 25 in. cross-section. Within this volume, sufficient filter media could be included to provide adequate dust loading.

Resistance to vibration and shock was as important in particulate filter design as filtration performance. Samples of commercial particulate filters were obtained and tested for vibration resistance. These filters were constructed similarly to MIL-F-51068[2]. Results indicated that commercial filters are marginal in their vibration resistance. A design program was undertaken to increase the resistance of particulate filters to shock and vibration.

Pleat spacers used for study were aluminum material, corrugated diagonally. When inserted between the filter media pleats, these spacers are oriented so that the corrugations run in opposite directions on opposite sides of the filter. Vibration tests on filters using these spacers and constructed per MIL-F-51068[2] produced media failures at the interface between media and the adhesive endseal material[6]. A decision was made to change the endseal material and framing.

The material selected for study was a plastisol that meets MIL-E-51065[7]. This specification limits the amount of allowable off-gasing. Continued evaporation of volatiles from a material could potentially damage the gas filter sorbent.

Plastisol, a dispersion of PVC (polyvinylchloride) in a plasticizer, exists as a viscous liquid in its uncured state. When heated, it forms a tough, pliable, impermeable material. Plastisol lends itself to use as an endseal material, since it will flow between the pleats, creating a reliable, leakfree bond to the media, spacers and outside framing.

Changing endseal material required use of channel-type frames rather than flat-sided, un-lipped frames, used with air-drying adhesives. Aluminum was chosen for strength and weight, while maintaining standard fabrication methods. At the time, a protective screen was added across both exposed faces of the filter.

Tests run on a prototype filter indicated that the filter could withstand the specified vibration and shock environment and the design was established for the optimum development models.

8 Gas Filter

The gas filter must be capable of providing complete protection against all toxic gaseous agents. As a measure of this protection, it must have a gas life greater than 20 min, when tested with 10 mg/liter of phosgene at its rated airflow. This 20 min is a minimum specification value and does NOT mean that these filters must be changed every 20 min during a chemical warfare attack. For specification testing, a very high concentration of agent is used so that the test will be relatively short. Under field conditions it is not possible to maintain a gas concentration of more than a fraction of the specified test concentration, and the gas lives will be orders of magnitude longer than the specified value. Since gas life testing with phosgene is a destructive test, Freon-12 was used as a nondestructive test for development purposes.

The sorbent specified for use in these gas filters is ASC Whetlerite per MIL-C-13724A[3] dated 1960. Two types of sorption are used in ASC Whetlerite: physical and chemical. Physical sorption depends upon condensation on a surface, while chemical sorption depends on either chemical reaction or catalytic decomposition of agents. Both depend on the gaseous molecules diffusing from the air stream and contacting the surface. The distance the gas is required to travel in the bed before every gas molecule contacts a removal surface is called the critical bed depth and is dependent on the granule size and density of packing in the bed. The critical bed depth is the minimum depth required to reduce the effluent concentration to zero. The dynamic capacity for charcoal used depends on its surface area and reagents added as treatment. From this information, the life of a charcoal bed can be calculated, for a given flow rate, using the Short and Pearce adaptation of the Mecklenburg equation[8], if a level of contamination is assumed. The gas life equation states:

$$T = K \frac{N_o}{C_o V_o} (\lambda - \lambda_c)$$

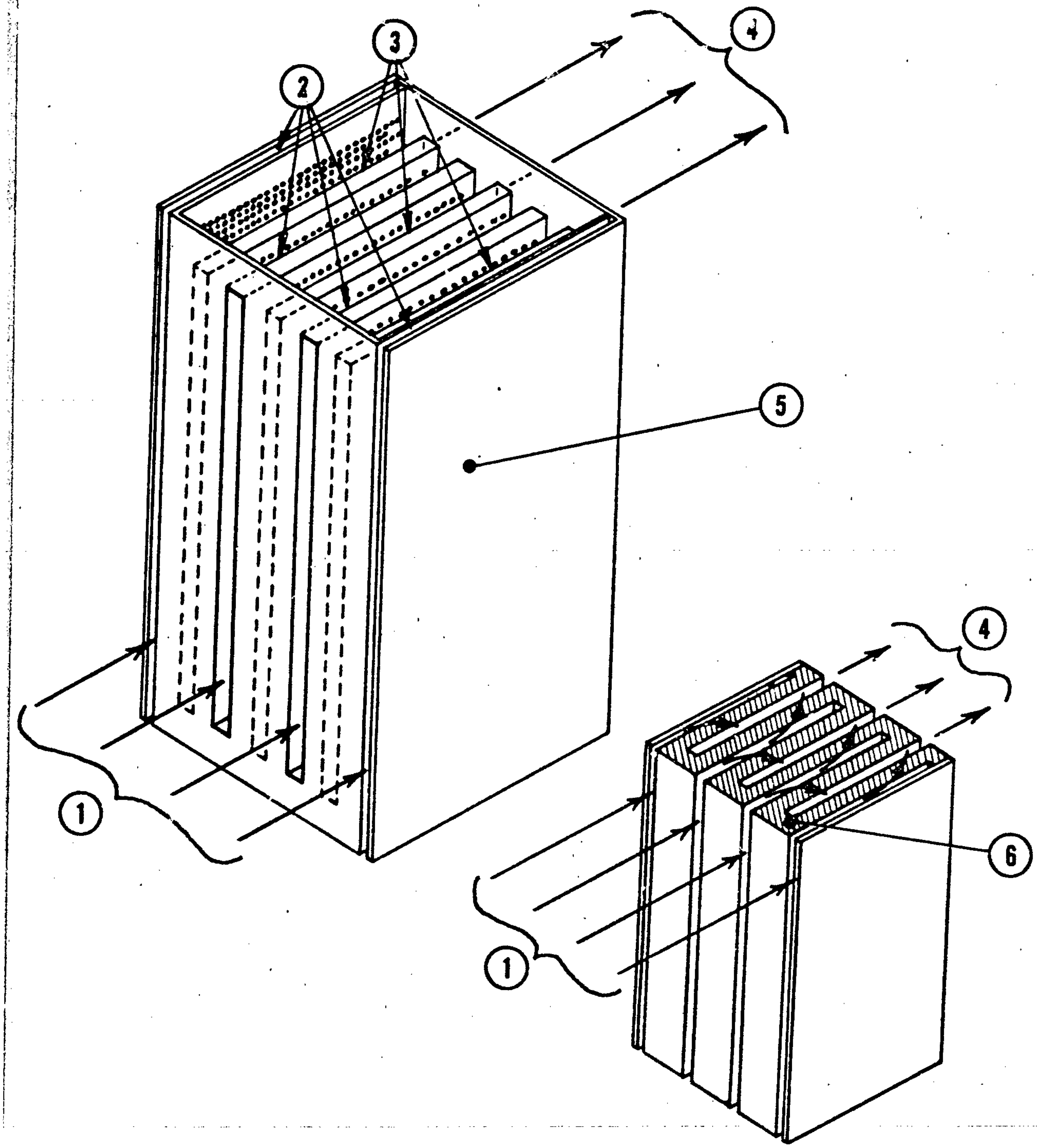
The values of N_o and λ_c must be determined for the sorbent used. This information for ASC Whetlerite was furnished by Edgewood Arsenal. In addition to gas life, two other design parameters concern bed thickness and pressure drop vs face area and pressure drop through inlet and outlet channels between the filter panels. This data is based on information presented in available literature and all gas life calculations were based on these assumptions.

The volume allotted for the gas filter can best be used with a gas filter having parallel, rectangular sides. In order to take advantage of this configuration, panel type gas filters were the logical choice; however, cylindrical and conical shapes were also considered. Since space requirements were so critical in this application, it was desirable to maintain a minimum entrance and exit area between the panels. This goal was complicated by the inherent problem of bowing of the perforated retaining material in normal panels. That is, the pressure exerted by the charcoal bed on its retaining structure causes that structure to bow outward. Normal methods of minimizing this problem consist of drawing the perforated metal faces of the gas panel together with a through-bolt. However, in this application the space requirements precluded such an approach. In order to eliminate this bowing problem, a unique design was developed.

The design approach used has been termed "Unitized Pack". This design eliminates the need for many sealing surfaces and individual components used in normal designs. In effect, the gas filter consists of a framework built up of fixed air chambers around which the charcoal is packed. A diagram of a vertical version of this unit appears in Figure 5. Note that the air inlet side of the pack contains two channels equally spaced from the sides and from each channel with an additional channel of half the normal width along each edge. These inlet air channels are separated from the three outlet channels by a 1.6 in. wide spacing. The lower sketch shows the volume not taken by the air chambers filled with charcoal. Air enters the four air inlet chambers on the upstream side of the gas filter, passes through the charcoal beds and out the three outlet chambers.

The problem of bowing of the perforated metal is eliminated in this design through the use of corrugated spacers within each air chamber.

The unitized pack design eliminates many problems inherent in other multiple pack designs, such as sealing and channelling. The sealing problem is circumvented by the use of charcoal surrounding an air chamber instead of an air chamber surrounding a charcoal bed. That is, if designed with usual methods, the six charcoal beds of the unitized pack would require six separate gaskets and a means of mounting the panels. Channelling is a potential hazard in any gas filter, but is minimized in this design. The only location in the entire pack having any significant probability of channelling is at the top. Thus, the chances for leaks around gaskets or channelling through the charcoal bed are greatly reduced in this design. Each of these affects the reliability of the unit.



1. Air Inlet
2. Air Inlet Chambers
3. Air Outlet Chambers
4. Air Outlets
5. Filter Shell
6. Charcoal

Figure 5. Unitized Gas Filter Concept.

Gas filters are also adversely affected by shock and vibration environments, with charcoal granule settling and/or attritition the primary problem. Settling, as used here, relates to a redistribution of the granules once they have been packed into the gas filter. Attrition is the disintegration of individual charcoal granules. Either condition has deleterious effects on gas filter life in two ways: (1) the potential for channelling is increased, and (2) movement of the granules erodes the charcoal fines retaining media mounted between the perforated metal and the charcoal granules. These effects are related to each other. If the charcoal bed settles until the granules can move relative to each other under vibration, the the particles wear through the fines retaining media and cause a failure by sifting out through the openings in the perforated metal. To alleviate this potential problem, the use of stronger fines material such as Nylon screen and nonwoven mats of glass fibers was studied. However, neither showed a substantial advantage over the cotton fines material normally used in gas filters.

Tests have shown that adequate charcoal granule retention extends gas filter life under vibration conditions. In order to increase life of the fines media, a study was made of a means of mechanically exerting a continuous spring pressure on the top of the charcoal bed. With this approach, as the charcoal bed settles due to redistribution or attrition of the granules, the top of the bed is continuously retained; limiting granule movement.

The entire area of charcoal granule retention and fines retaining media appears to offer further potential for development work. For example, the woven cotton cloth and perforated metal now used might be replaced with fines screen, sintered metal, fiber metal or other materials. Various potential means for retaining the granules also exist.

The filters developed during the Feasibility Phase withstood 24 hr exposure to shock and vibration as specified in Appendix B of the contract. However, gas filters differ from other mechanical parts, for which the shock and vibration specification was written. For example, fatigue failures of normal mechanical parts due to improper design will become evident during tests specified in Appendix B. Gas filters, however, are subject to continuous degradation. Failure incidence of the fines retaining media is more dependent upon number of cycles than the intensity of the stress. Therefore, gas filter acceptance to the contract specified requirements do not necessarily meet the intent of the requirements.

The nominal 96 lb weight of the gas filter caused some concern from a human factors standpoint. As a rule of thumb, any component requiring frequent replacement or maintenance should weigh less than 100 lb, so one man can handle the item.

A study was made to determine the feasibility of splitting the gas filter into two parts for easier handling. It became obvious that a split filter required extensive design concessions. Splitting the gas filter either horizontally or vertically requires --

-- 0.9 in. additional length in the Filter Unit.

-- attachment to the ECU over the entire end of the Filter Unit, not just across the top half.

-- more care in sealing, due to additional sealing surfaces.

Thus, splitting the gas pack appeared to have too many disadvantages to be considered further.

9 Blast Closure Device

The blast closure device was required to provide complete protection to Filter Unit components from blast forces. The closure device should include a shock wave sensor, a trigger to initiate closure of the device, an actuating mechanism to complete closure before damage can occur to the Filter Unit, a latch or residual force to prevent reopening during the negative pressure phase of a blast, and a reopening mechanism to permit renewed operation of the Filter Unit. In addition, the device must meet the requirements of Appendix B1 of the contract and the pressure drop through the device must not degrade Filter Unit performance, due to inlet geometry. Contract Modification No. 5 specified a concept study to investigate the possibility of a combination antiblast closure/deep-fording valve.

The required actuation time for the closure device was defined as the time from the initial sensing of the blast until the seal is secure and no further leakage can occur. This includes the time for the sensor to provide a signal, time for the actuating mechanism to be triggered and the time for the actuating mechanism to complete the motion to provide a seal.

In order to obtain the rapid closure required to minimize pressure wave passage during the closing operation, some source of stored energy is required. Electric motors or gear drives would not provide the required closure time. The following sources were considered, either singly or in combination: Pneumatics - high and low pressure; hydraulics; springs; explosive actuators; solenoids; and shock wave.

The time necessary for the opening operation of the antiblast closure was not a critical factor in design. Therefore, the following methods for opening the antiblast closure were considered; pneumatics, hydraulics, springs, electric motor - gear drive, electric motor -

screw drive, electric motor – cam drive, and solenoids. A holding provision in both the open and closed position provided several distinct advantages. A latch in the open position would eliminate a need for continuous power output to hold the valve open and provide maximum resistance to the shock and vibration environment. A latch or residual force in the closed position would prevent valve rebound during closing and maintain the seal during the negative pressure phase. However, for a closure actuated by the shock wave it was required to override the open-position latch with shock wave overpressure. In addition, a means of manually releasing the closed-position latch was necessary.

It was the intent of the design approach to minimize size and weight and to optimize compatibility of the antiblast closure to the Filter Unit design, with a minimum retrofit of units. Also the design must minimize the possibility of accidental closure by natural phenomenon such as wind, lightning, shock and vibration. The open-position latch would prevent accidental closure from shock, including movement over rough terrain and firing of the weapons system.

Five design concepts, all shock wave actuated, were defined for the closure device (reference Report No. 17[36] for detailed concepts):

Concept A: A combined antiblast closure/deep-fording valve, using a motor driven cam and cam follower for operation as a deep-fording valve and an air piston-ball latch for antiblast closure operation. The device is actuated as a deep-fording valve when the drive motor is actuated from the control panel in the crew compartment. The antiblast mechanism remains in the latched position during use as a deep-fording valve. The device operates as an antiblast closure when the shock wave pressure impinges on the air piston. This results in a short motion (0.060 inch) of the air piston and actuator rod, releasing the ball latch mechanism. The closure cover is released and moves down to close the inlet. The motion of the closure cover assembly actuates the drive motor and turns the cam and cam follower to the downward (closed) position, resetting t ball latch mechanism and air piston assembly. Actuation from the crew compartment initiates reopening and the device is ready to operate again as a deep-fording valve or antiblast closure.

Concept B: A combined antiblast closure/deep-fording valve, using a motor driven cylindrical cam for operation as a deep-fording valve and a spring loaded cam follower and sloped cam ramp for antiblast closure operation. The device is actuated as a deep-fording valve when the reversible drive motor is actuated from the control panel in the crew compartment. To open the valve the reversible motor turns the cylindrical cam 360 degrees clockwise. The cam follower is forced up the cam ramp until it reaches the cam indent, and

the valve is in the open position. To close the valve, the drive motor turns the cam 360 degrees counterclockwise and the operation is reversed. The device operates as an antiblast closure when a shock wave pressure impinges on the closure cover with sufficient force to compress the cam follower spring and cause the cam follower to jump out of the cam indent, slide down the antiblast ramp, and catch in the lower cam ramp. Activation from the crew compartment initiates reopening and the device is again ready to operate as a deep-fording valve or antiblast closure.

Concept C: A combined antiblast closure/deep-fording valve, using a drive motor-drive screw combination for operation as a deep-fording valve and a conical spring and spring latches for antiblast closure operation. The device operates as a deep-fording valve when the reversible drive motor is actuated from the control panel in the crew compartment. The antiblast closure mechanism remains in the latched position during use as a deep-fording valve. The device operates as an antiblast closure when the shock wave pressure impinges on the closure cover. The pressure on the cover overcomes the spring latches allowing the conical spring and shock pressure to drive the cover closed. The drive screw and spring plate remain in the extended position during antiblast closing. The motor switch actuator moves down with the cover, actuating the drive motor. The drive screw and spring plate are retracted by the drive motor, compressing the conical spring until it reaches its latched position. The device can be reopened from crew compartment control panel.

Concept D: A combined antiblast closure/deep-fording valve incorporating the three drive screws driven by a reversible motor, as used in the current design deep-fording valve, and the air piston-ball latch mechanism, used in Concept A. The device operates as a deep-fording valve when the reversible drive motor is actuated from the control panel in the crew compartment, driving the drive screws and closure cover up or down. The device operates as an antiblast closure when the shock wave pressure impinges on the air piston. The air piston and actuator rod are forced down, releasing the ball latch mechanism and thereby releasing the closure cover assembly. The shock pressure and springs force the cover closed. The three drive screws remain in the extended position during antiblast closing. A motor switch actuator rod actuates the drive motor, retracting the drive screws, and resetting the ball latch mechanism and air piston assembly. The device can be reopened from the crew compartment control panel.

Concept E: Located in the precleaner section, immediately upstream of the particulate filter. The closure consists of a set of light weight louvers, interconnected, and spring biased to remain open during normal operation. The pressure differential across the

louvers resulting from a shock wave would cause the louvers to close and remain closed until the differential pressure was reduced to a predetermined level. The bias springs would then reopen the louvers, allowing normal flow. With this type of antiblast closure, the deep-fording valve would be used in the inlet.

As a result of blast hazard testing (See Section VI) of the Filter Unit, it was determined that a closure device was not required for the blast pressure level specified and all further design effort was halted.

10 Control Panel

Primary design requirements for the control panel are that it must provide a means to control, monitor, and indicate Filter Unit operation. These functions are achieved through control and indication of the status of individual components and conditions, including the deep-fording valve, fan, airflow control valve, filter restriction level, and crew compartment pressure level. The control panel must also provide general system protection by indicating any existing caution or danger condition within the system.

Secondary design requirements include water and splashproofing of components, quick disconnects for maintenance, automatic reset of alarms, and fail-safe warning.

Design logic for the control panel was agreed upon through coordination with representatives of CRDL, Army Tank-Automotive Command (ATAC), and the Human Engineering Laboratories at Aberdeen Proving Ground. This resulted in the panel layout, including panel wording, color of indicators, and types of switches.

Human Factors Engineering Branch of CRDL conducted an analysis of the man-machine relationships involved in remote control of the Filter Unit. As a result; panel color codes, labeling, legend, indicator size, types of switches and indicators, etc; were proposed considering factors of space availability, legibility, simplicity, and economy.

Electronic, electro-mechanical, or mechanical switches could provide the necessary controls. Visual, audio, or audio-visual indicators could provide the necessary monitoring function. Fuses or circuit breakers could provide the necessary system protection.

Lighted pushbutton switch/indicators approved by ATAC were selected for system controls. The decision to use this type was based on space requirements of the control panel and lighting conditions of the crew compartment. This type of switch combines both switch and indicator in a single unit resulting in a compact control panel. Since they are self-illuminated, these switches can be operated in the absence of adequate ambient lighting.

Lighted indicators were selected for use in conjunction with the lighted switches to provide the necessary monitor function. These would indicate system status in the case of any warning or danger conditions.

Since crew compartment pressure is of prime importance, a warning horn was included in the design to provide audio as well as visual indication of a danger condition. The audio warning would attract attention in the case of unattended operation of the Filter Unit.

System protection would be provided by circuit breakers in the controlling circuits. Circuit breakers rather than fuses were selected since it would be necessary to provide spare fuses in the panel. The design also includes visual indication of circuit breaker status.

It was decided to include an hourmeter in the control panel as an aid in periodic maintenance of the fan assembly.

Human Factors Engineering of the control panel resulted in the addition of the following items to the panel design.

A pushbutton switch to turn off the visual warning device.

A pushbutton switch to turn off the audio warning device.

A control to adjust the brightness of illuminated indicators and controls.

A pushbutton switch to check all panel indicator lamps.

A storage space for spare indicator lamps.

Two physical configurations of the control panel were possible; the switches and indicators could be a part of the vehicle controls - by incorporating into a master control panel - or the switches and indicators could be grouped into a separate panel as part of the Filter Unit.

Because of lack of knowledge of the final vehicle design, it was decided that the separate panel approach would be the better. With this design; the switches, indicators, and associated circuitry would be housed in a splashproof and dustproof protective box.

The specified mounting location of the Filter Unit was external to the crew compartment . Therefore, it was required that the control panel be a separate unit, in order to provide remote control capability. This panel would mount within the crew compartment and would connect to the Filter Unit through a control cable.

The following section describes how the preceding concepts were incorporated in the design of the E49 Filter Unit and components.

V FILTER UNIT DESIGN

A INTRODUCTION

The design of the E49 Filter Units and components evolved through four stages; from the Breadboard Models, Working Models, and Optimum Development Models, during the Feasibility Phase of the contract to the Preproduction Models during the Development Program Phase of the contract. The following paragraphs describe the Preproduction Model design in detail, with a summary of the design changes since the earlier models.

B FILTER UNIT DESIGNS

1 Breadboard Models

Prior to fabrication of the Working Models, a Breadboard Model Filter Unit was built to determine the most feasible arrangement of unit components. The Breadboard Model housing was constructed of plywood containing retaining mechanism models constructed of metal.

This model was thoroughly evaluated for design. Changes, as a result of this evaluation, were incorporated in the buildup of Working Models.

2 Working Models

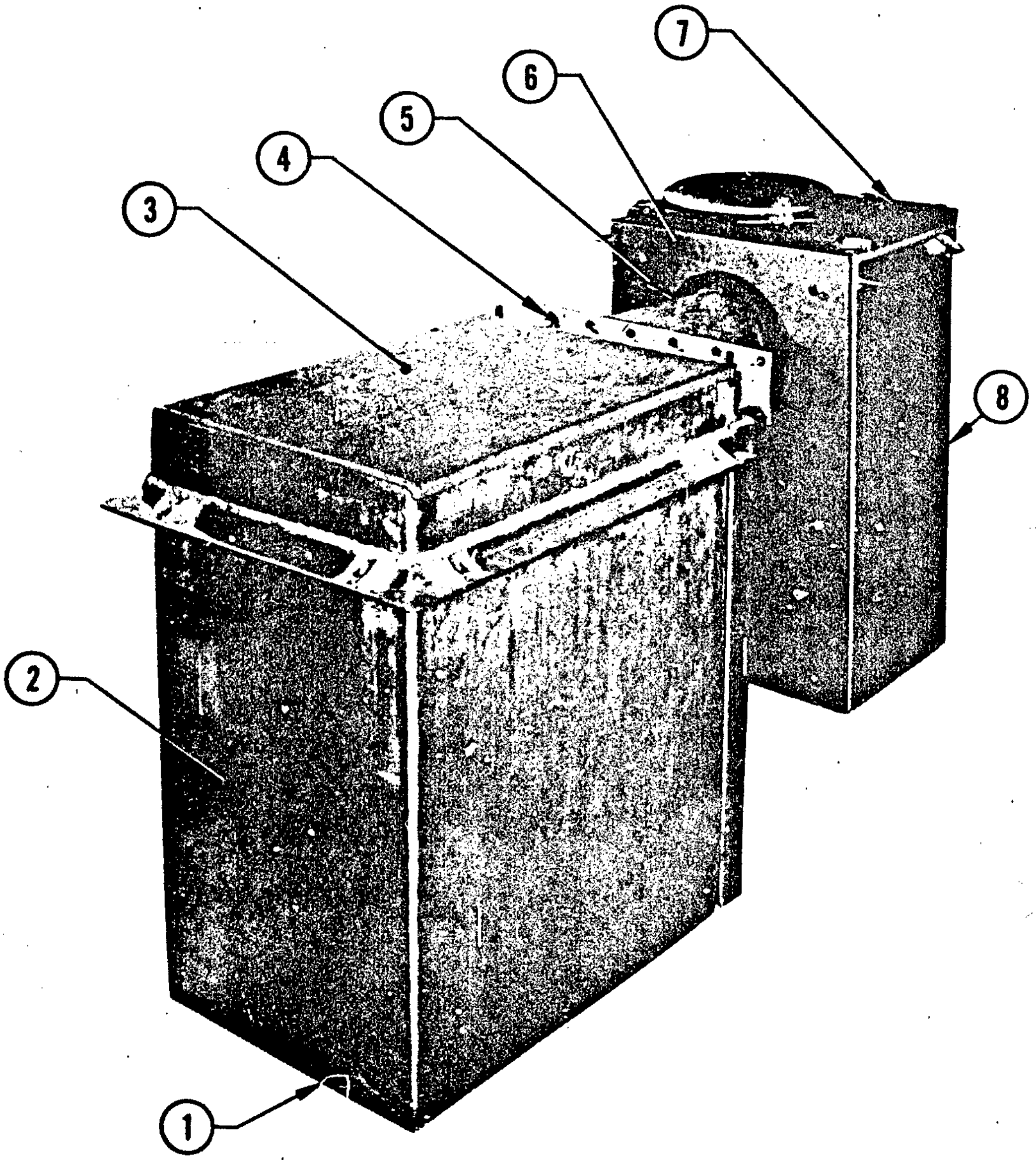
Two each of two distinct Filter Unit designs were fabricated as Working Models. These were the integral E49 Filter Unit and the split design E50 Filter Unit.

a. E49 Filter Unit

The E49 Filter Unit Working Models basically resembled the later Preproduction Models with the exception that refined techniques, primarily in tooling, were used in fabrication of the Preproduction Models. The Working Models contained all basic design parameters, including gas and particulate filters mounted within one section of the housing and the precleaner in the other section of the housing. This unit was constructed primarily for evaluation of function and performance.

b. E50 Filter Unit

The Feasibility Phase also carried a parallel development program for a Filter Unit capable of being mounted in two separate modules, if desired. The requirement was initiated when the specified length for a completely self-contained Filter Unit was established at 20 in. This alternate design provided that the particulate and gas filters be mounted in one self-contained module, (2) Figure 6. The precleaner mounted remotely in its own separate module (8) and connected to the filter module by ducting (5). This design was designated Filter Unit, Gas-Particulate, Tank, EMD, 400 CFM, E50.



1. Filter Module
2. Air Outlet
3. Filter Access Cover
4. Filter Module Inlet Adapter
5. Transition Duct
6. Precleaner Module Outlet Adapter Plate
7. Precleaner Cover
8. Precleaner Module

Figure 6. Gas-Particulate Filter Unit, Tank, EMD, 400 CFM, E50.

In this configuration the precleaner module (8) measures 26 in. high x 14.5 in. wide x 10.6 in. long, exclusive of the mounting flange. The filter module and its inlet adapter (2) measure 26 in. high x 14.6 in. wide x 26 in. long, exclusive of the mounting flange. Both filters and precleaner mount into their respective modules as in the E49 Filter Unit. The E50 Filter Unit has the same components - E62 precleaner, E59 particulate filter, E61 gas filter, and E67 control panel - as the self-contained version. Operation is also identical.

In the working model version of the E50 Filter Unit, a flat adapter plate (6) fits over a 19.6 x 9.7-inch opening in the precleaner module, creating a 5 in. round outlet. A 2 in. deep plenum chamber (4) attaches upstream of the filter module providing a 11.5 in. x 1.5 in. inlet. Air must be ducted from the precleaner to the filter module, mating the round opening on the one end and the rectangular opening on the other. The outlet of the precleaner module and inlet to the filter module could be located in various locations to facilitate integration into a specific vehicle. The interconnecting duct not only contains the airflow, but also the pressure tubes running from the fail-safe filter sealing channels and the crew compartment pressure tap. No electrical connection between the two modules is required.

As an alternate to the remote precleaner module installation, the two adapters can be eliminated, allowing the precleaner module to attach directly to the filter module to become, in effect, an E49 Filter Unit configuration. In this configuration, the overall length is 30.5 in.

3 Optimum Development Models

Four Optimum Development Models of the E49 Filter Unit were fabricated from Class II drawings. The major difference between this model and the Working Model was the refinement of component design and fabrication methods. Table 1 lists the major design changes between this model and the earlier Working Models.

4 Preproduction Models

Figure 1 illustrates the Preproduction Model E49 Filter Unit complete with E67 control panel. Electrical power enters the Filter Unit through the same electrical connector used for cable connection to the control panel. Figure 7 is an exploded view of the basic removable Filter Unit components showing their relationship in the housing. The filter access cover (3) seals the filter section of the housing while the precleaner (7) has its own cover built into the assembly.

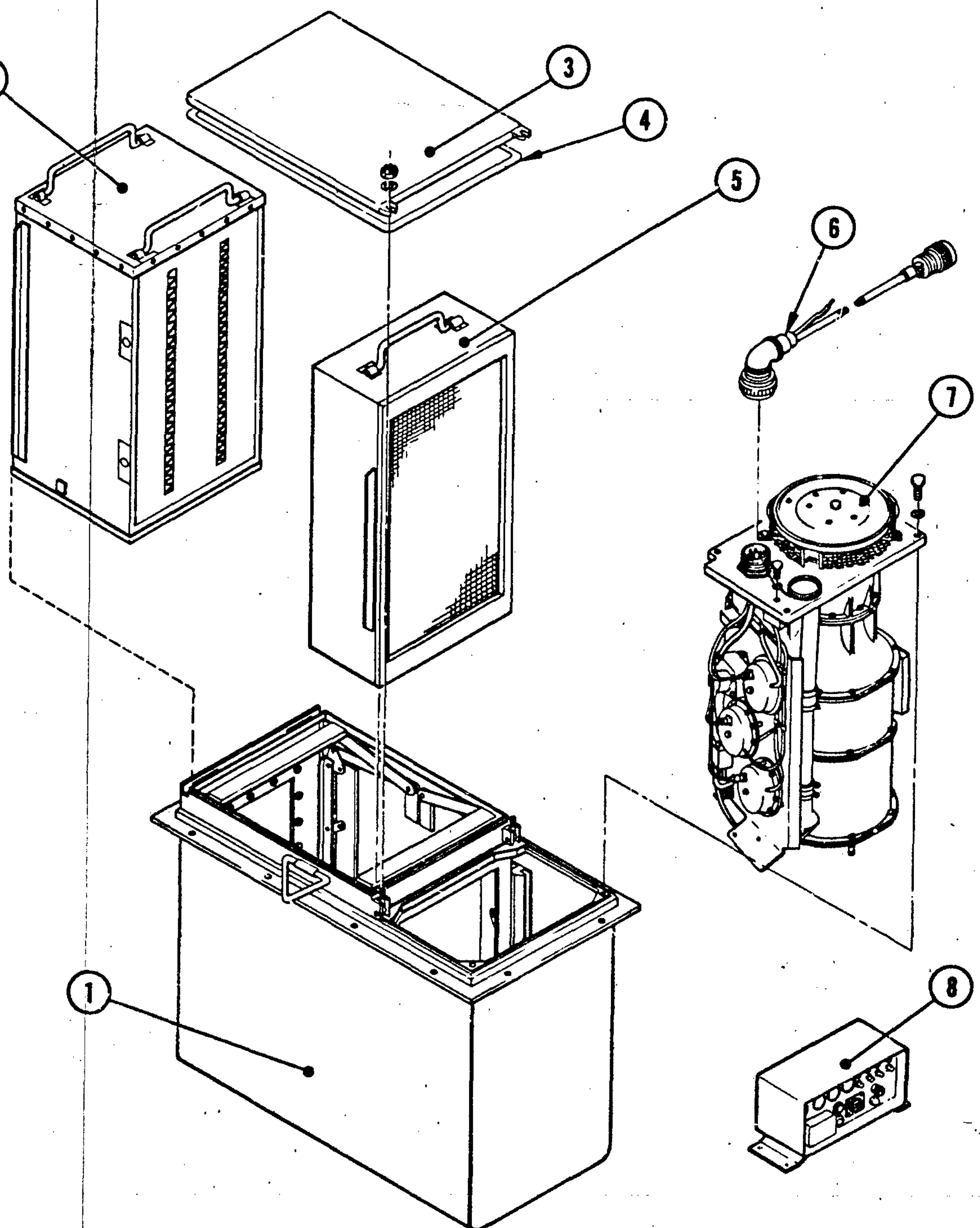
TABLE 1. WORKING MODEL FILTER UNIT MAJOR DESIGN CHANGES

Revision	Working Model	Optimum Development Model	Reason
Precleaner Cover	No inlet screen	Inlet screen	Prevent large obstructions from entering Filter Unit.
Precleaner Cover	Lifting handle secured to precleaner cover with bolts and clip fastener.	Lifting handle attached to inlet screen with bolts and clip fasteners.	Accessibility.

Twelve Preproduction Models were fabricated. Six of these units have a mounting flange, as illustrated, and six units were fabricated without a mounting flanges for possible change of installation in the MBT 70. Table 2 contains the major design changes between this model and the earlier Optimum Development Model.

TABLE 2. PREPRODUCTION FILTER UNIT MAJOR DESIGN CHANGES.

Revision	Preproduction Model	Optimum Development Model	Reason
Air Outlet Size	8.0 x 13.25 inches	7.62 x 8.25 inches	To mate with ECU air inlet.
Filter Access Cover	2 cover tabs	3 cover tabs	Cost reduction.
Pressure Sensing Network	Failsafe Y at channels	Failsafe Y at disconnect	Less machining on disconnect block and less pressure tubing.
Mounting Flange	Flange surrounding upper housing	None	Mounting convenience.
Lifting Eyes	Two	None	Installation convenience.
Warning Label	Warning label for servicing components after chemical exposure	None	Human Engineering.
Retaining Mechanism	Heavier pins, mounting pads, shock pads, and handles	- - - - - -	Provide better resistance to 30 g shock.
Particulate Filter Keying Guide	Added angle to guide filter during installation	None	Foolproof installation.



1. Filter Unit Housing
2. Gas Filter
3. Filter Access Cover
4. Cover Gasket
5. Particulate Filter
6. Power/Control Cable
7. Precleaner
8. Control Panel

Figure 7. E49 Filter Unit Exploded View.

5 Design and Performance

The Filter Unit provides a clean air supply for the crew compartment of certain military combat vehicles. The unit provides purified air and positive crew compartment pressurization to prevent entry of toxic gases or aerosols through leakage and during firing operations. The Filter Unit inlet is sealed during vehicle fording operations by means of a motorized deep-fording valve.

The precleaner assembly contains air delivery and control components. A fan assembly provides pressurized air to the Filter Unit. A dust separator removes the majority of dust particles which are ejected overboard through a dust exhaust tube, using a portion of the fan airflow for dust exhaust. A motorized airflow control valve automatically regulates the airflow to maintain a crew compartment pressure level of 1 to 1.5 inch wg above atmospheric pressure. The pressure control system includes pressure switches and the airflow control valve.

The air must pass through a particulate filter (5) and a gas filter (2) for purification before reaching the environmental control unit, if the vehicle is so equipped, otherwise it passes directly to the crew compartment of the vehicle. The operation of the unit is controlled, from the control panel in the crew compartment.

The Filter Unit operates on 27.5 vdc power, supplied from the vehicle power source.

The following characteristic data is approximate:

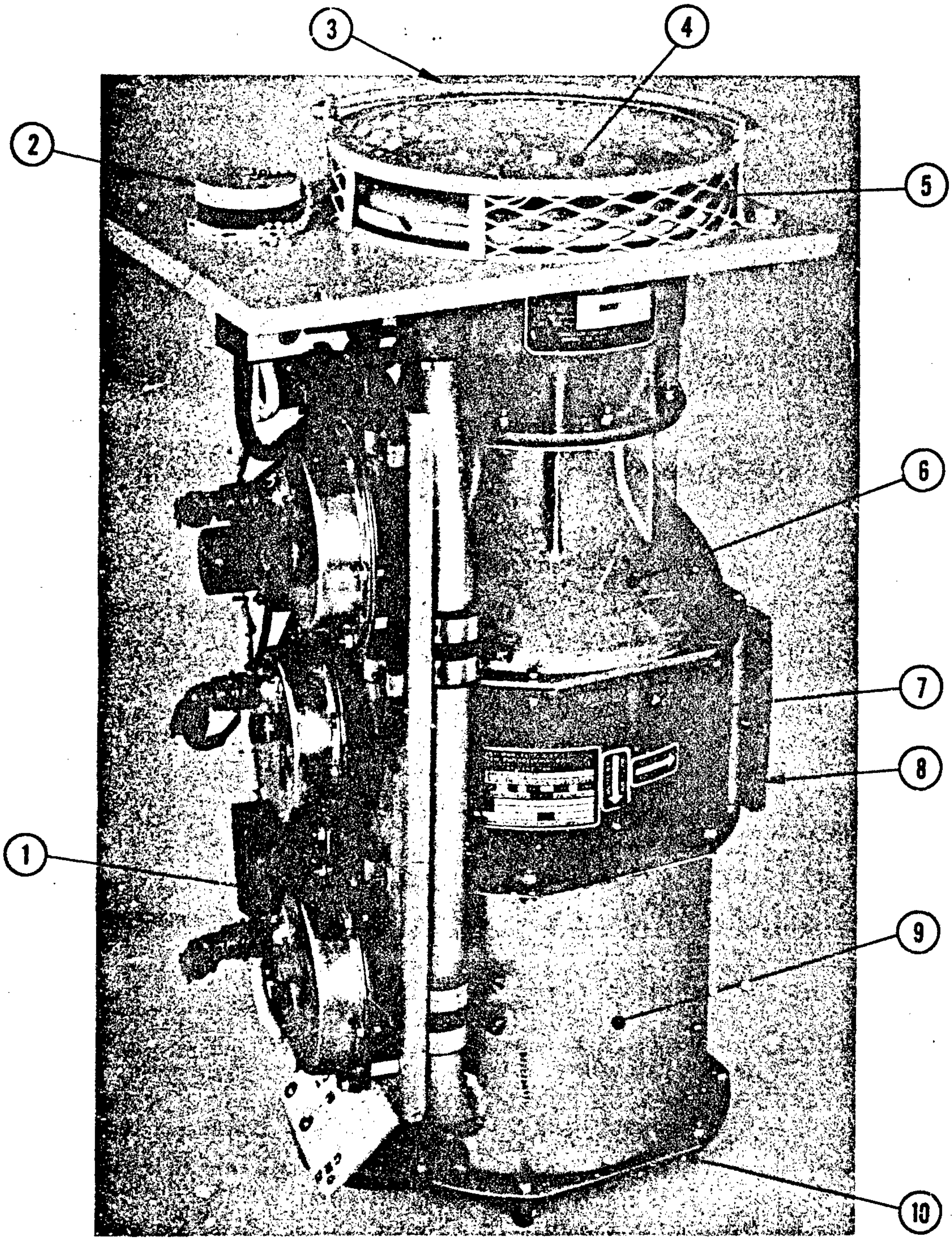
General	
Total Volume (Including control panel)	6.6 cu ft
Total Weight (Including control panel)	258 lb
Rated Air Flow	400 cfm
Dust Exhaust Flow	40 cfm
Varying Flow from	135 cfm
to	400 cfm
Maximum Fording Depth	24 ft
Operating Temperature Range	-65°F to +125°F
Dimensions (Filter Unit Only)	
Height	26 in
Length	30 in
Width	14.5 in

Electrical System	
Type	27.5 vdc
Current Required	87 amps
Construction	
Welded aluminum	
Performance	
Dust capacity (at 0.025 gm/cu ft of AC Coarse Test Dust)	
400 cfm	24 hr minimum
200 cfm	130 hr minimum
Aerosol efficiency 99.97 percent (minimum)	
Gas filter life equal to standard service mask	
Gas-Particulate Filter Section	
Volume	4.4 cu ft
Weight (Unit Housing)	75 lb
Particulate Filter	15 lb
Gas Filter	96 lb
Precleaner	
Volume	2.0 cu ft
Weight (Excluding Housing)	64 lb
Fan Type	Mixed Flow
Control Panel	
Volume	0.2 cu ft
Weight	7 lb

The following paragraphs describe the design of components for the Preproduction Model E49 Filter Unit. The Feasibility Study Report[10] and Design Study Report[4] contain detailed descriptions of component design for the Optimum Development Models and Working Models respectively.

C PRECLEANER, E62

The E62 440 cfm precleaner assembly (Figure 8) consists of a deep-fording valve (4), a fan (6), a mechanical dust separator (9), a motorized airflow control valve (10), and a component panel (1) containing various controls. The precleaner assembly is contained within the primary section of the Filter Unit housing.



1. Component Panel
2. Bulkhead Connector
3. Lifting Handle
4. Deep-Fording Valve
5. Prescreen
6. Upper Fan Housing
7. Lower Fan Housing
8. Keying Boss
9. Dust Separator
10. Airflow Control Valve

Figure 8. Precleaner Assembly, 440 CFM, E62.

The deep-fording valve has a sealing cover which is opened and closed by a reversible direct current motor. Limit switches stop the motor when the sealing cover reaches the fully open and closed positions. A rubber boot between the cover and gear housing serves as a dust protector.

The fan assembly consists of a fan driven by a 27.5 vdc motor. The fan and motor are contained in a cylindrical housing. The fan provides 440 cfm airflow at 20 inches of water.

The dust separator contains mechanical separator tubes which remove the majority of dust particles.

The airflow control valve consists of a movable and a stationary plate with spiral slots. The movable plate is powered by a reversible direct current motor. A 180 degree rotation of the movable plate closes the spiral openings, decreasing the air supply to the crew compartment. High and low pressure switches monitor the crew compartment pressure level and initiate operation of the airflow control valve.

The component panel assembly contains the electrical components which control operation of the unit. A filter restriction switch measures the restriction across the filters and activates a warning indicator on the control panel. The high and low pressure switches measure crew compartment pressure. The pressure level is maintained within the desired range by opening or closing the airflow control valve. A radio frequency noise suppressor filters stray radiation from the fan motor to prevent communication interference in the vehicle. The airflow control valve motor has two RFI suppressors. A fan motor overload sensing control will shut down the unit, if an excessive current draw occurs, to prevent damage to the motor. A fan motor power relay provides a switch for remote operation of the motor. A control circuit relay provides the necessary controls to the low pressure switch.

The Filter Unit air inlet is surrounded by a screen (5) to prevent ingestion of leaves, twigs or other matter which could cause damage to the fan assembly, plug the dust separator tubes, and/or prevent the fording valve cover from sealing the inlet. The screen consists of expanded metal with relatively large openings which do not cause appreciable pressure drop.

The handle (3) used to lift the precleaner from its housing attaches to angles along the side of the screen. When not in use, the handle snaps beneath a spring clip.

The precleaner cover also provides the mounting surface for the electrical power/control cable and the upper half of the pressure tube manifold.

The precleaner cover provides a mounting for the deep-fording valve assembly within the air inlet throat. The deep-fording valve assembly mounts within the throat on three legs which mate with bosses cast into the throat.

The fan assembly (6, 7) mounts immediately below the air inlet throat and the dust separator/airflow control valve assembly (9, 10) attaches below the fan assembly. The component mounting panel (1) also attaches to the fan assembly.

D DEEP-FORDING VALVE, E70

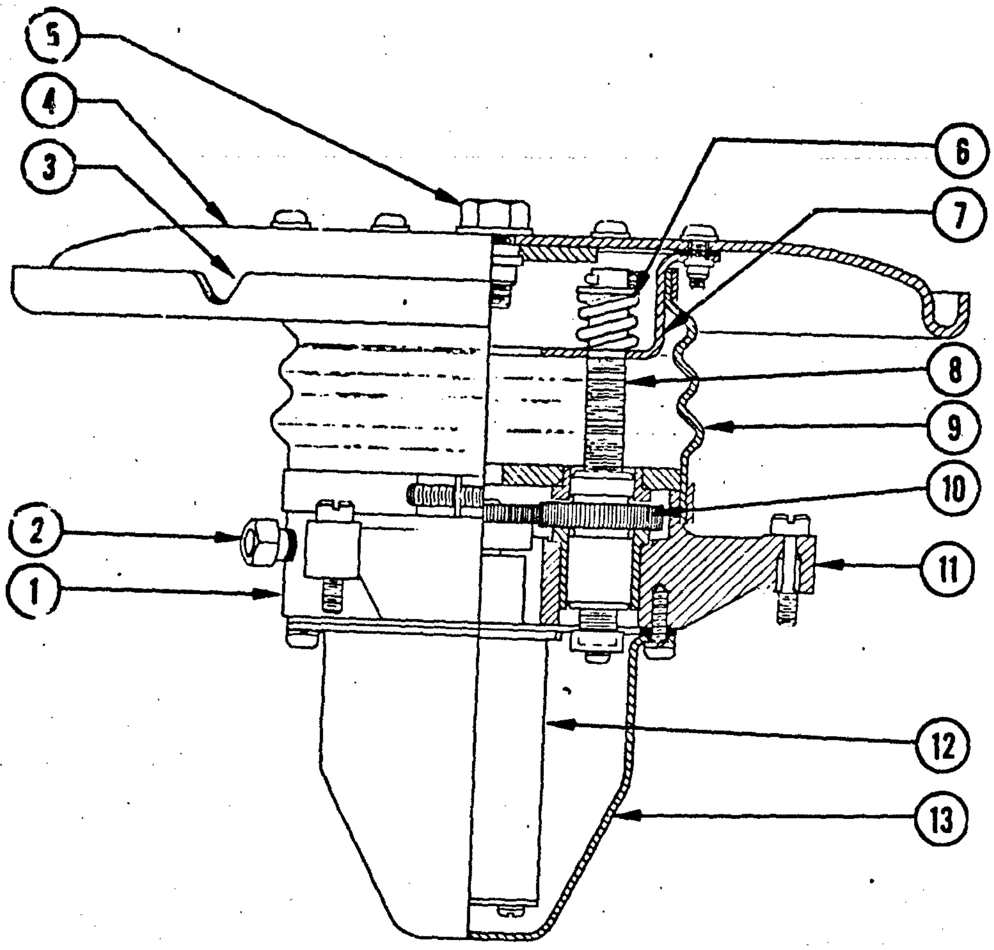
The deep-fording valve, Figure 9, seals the Filter Unit inlet during nonoperating conditions and during deep-fording. The following detailed discussion describes the design and function of the valve in relation to Figure 10, a cross-sectional view of the valve.

The fording valve mounts within the air intake throat of the precleaner by three legs (11) which protrude from the gear housing (1) and fasten to bosses in the air inlet throat. In the open position, with the precleaner operating, the cover is held 1 inch above the sealing gasket, providing an annular open area of 27.9 sq in. The distances between other parts of the deep-fording valve and the inlet air throat are kept maximized to minimize airflow restriction.

When sealed, the fording valve cover (4) rests against a sponge rubber gasket on the precleaner cover. This seals the main air intake, scavenging flow outlet, and atmospheric pressure tap during deep-fording. The cover is formed with a lip around the periphery to minimize entry of water into the Filter Unit during operation in rain. This prevents water from flowing over the edge and into the air inlet. Water which does collect on the cover drains off at a notch (3) positioned directly over the scavenging air exhaust. The drain off at this point is forced away from the air intake by the exhaust airflow.

1. Motor Dust Protector
2. Mounting Leg
3. Valve Cover
4. Electrical Connector

Figure 9. Deep-Fording Valve, E70.



1. Gear Housing
2. Sintered Metal Breather
3. Water Drain Notch
4. Cover
5. Drive Motor Access Bolt
6. Compression Springs
7. Retainer Cup
8. Threaded Shafts (3)
9. Rubber Boot
10. Planetary Gear (3)
11. Mounting Legs (3)
12. Drive Motor
13. Dust Cap

Figure 10. Deep-Fording Valve Cross-Section.

The deep-fording valve is controlled from the crew compartment by the UNIT ON/DO NOT FORD switch on the control panel. When the switch is depressed, the circuit to the fording valve drive motor (12) is closed. This planetary gearhead motor operates on 27.5 vdc, drawing approximately 0.8 amp and producing 17 in.-oz torque. The drive motor output shaft rotates at 450 rpm. The spur gear fastened to the drive motor output shaft turns the three planetary gears (10) in unison. This raises the cover, since the threaded shafts (8), which pass through the center of the planetary gears, are prevented from turning by flattened sections on the shafts which engage slots in the cup (7). The opposite end of the threaded shafts contain cup-type washers which actuate the limit switches. Just prior to reaching the full open position, a limit switch is actuated, closing the circuit to the fan motor, allowing the fan to start. After approximately 0.09 inches further travel of the cover, a second limit switch is actuated which opens the circuit to the drive motor. This stops the cover travel and the fording valve remains in the open position until the Filter Unit is turned off. The opening sequence requires less than two seconds.

When the UNIT ON/DO NOT FORD switch is again depressed, the circuit to the fording valve drive motor closes and the motor operates in the opposite direction, lowering the fording valve cover. The limit switch controlling the fan motor is deactuated and stops the fan when the cover lowers about 0.09 inches. The cover continues downward until the outer periphery contacts the sponge rubber gasket on the precleaner cover. The threaded shafts continue to travel, compressing the springs (6) attached to the top of the shafts. These springs apply additional pressure against the rubber gasket, compressing it to about 25 percent of its original 5/16-inch thickness. Actuation of a limit switch stops the fording valve drive motor after the threaded shafts have travelled an additional 0.2-inch downward.

The compression springs serve a threefold purpose; they allow for uneven closing of cover without straining the shafts, they allow for over-travel of shafts, making adjustment of limit switches less critical, and they allow for further travel of the cover during deep-fording operation without placing an axial load on shafts and gears. Each spring is rated at 16 lb force which provides a potential of 48 lb force. Under deep-fording, this force is increased because of added pressure of the water.

The closing sequence also requires approximately two seconds. Proper sealing is indicated on the crew compartment control panel.

The lower portion of the fording valve, containing the drive motor and switches, is protected from dust and mishandling by a dust cap (13) fastened to the gear housing. The upper portion of the fording valve is sealed by a rubber boot (9) fastened between the retainer cup and the gear housing with band clamps.

A sintered metal breather filter (2) in the gear housing allows the boot to breathe as the cover is raised and lowered. Without this, the boot tends to collapse because of the vacuum drawn by raising the cover.

The electrical cable is sealed at its point of egress from the gear housing by a rubber bushing, compressed around the cable. The end of the cable terminates in a bulkhead type fitting fastened through the wall of the precleaner cover air inlet throat.

The fording valve drive motor contains no radio frequency suppression filter. Elimination of a radio suppression filter was justified, since the valve only operates when starting or stopping operation of the Filter Unit.

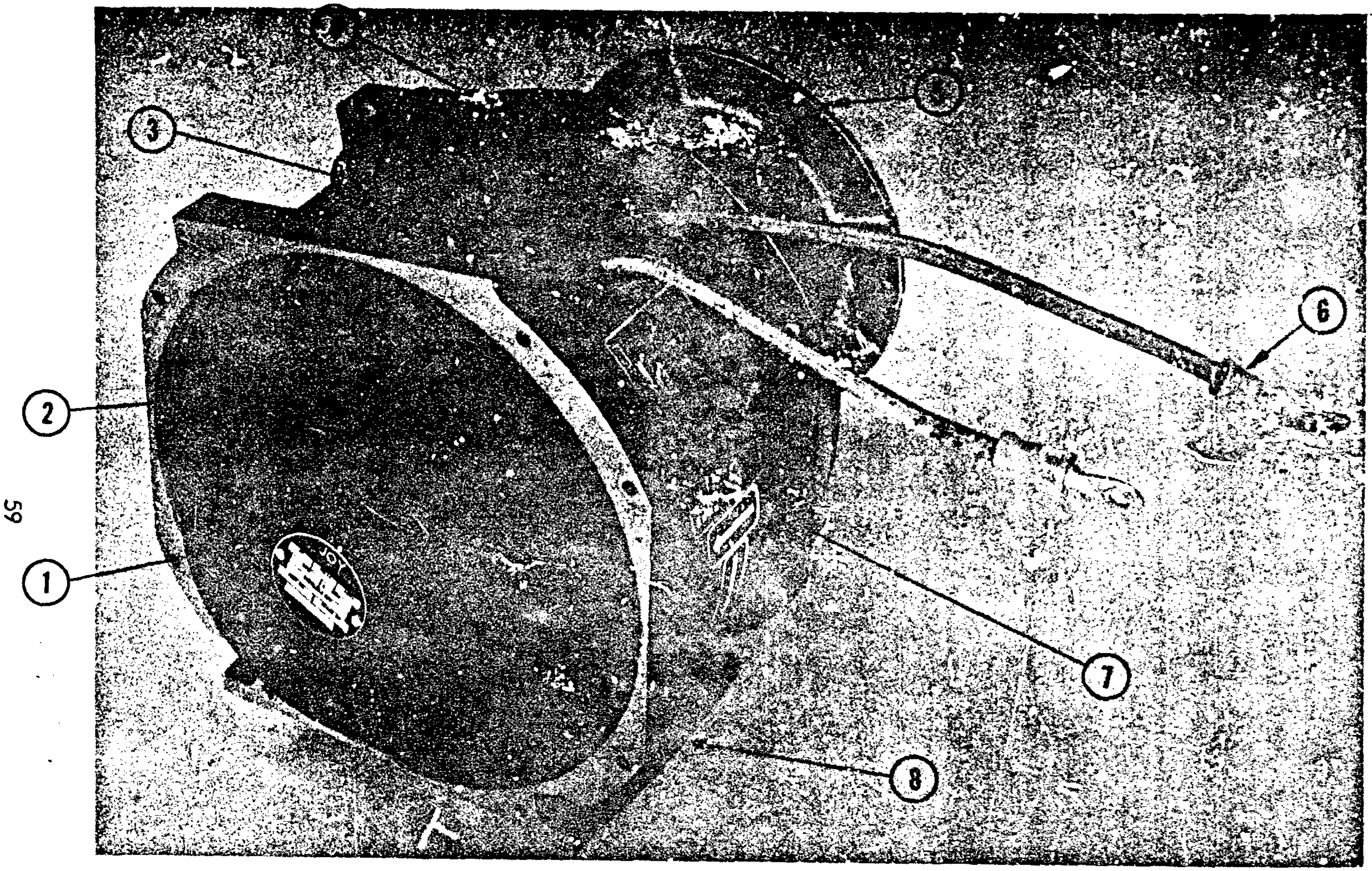
In case of a drive motor failure, the fording valve can be manually opened or closed by removing the bolt (5) in the cover. This allows access to the end of the drive motor shaft which is slotted to accept a screwdriver. By turning the drive motor clockwise, the cover can be lowered. Counterclockwise rotation raises the cover.

Reliability of sealing is enhanced by the high closing force created by the mechanical advantage from the screws and gears. The gears and drive screws also provide a self-locking feature in both the open and closed position without constant power output.

E FAN, MIXED-FLOW, 440 CFM

The fan, Figure 11, provides air to pressurize the vehicle crew compartment. It is a mixed flow type fan, rated at 440 cfm at 20 in. water with a 27.5 vdc series-wound electric motor. The motor dust cap (1) has a series of radial fins (2) which extend into the airflow to dissipate heat. The downstream end of the flow straightening vanes are visible within the housing.

The fan assembly upper flange (5) attaches to the lower flange of the air inlet throat with bolts and is sealed with a 1/16-inch thick neoprene gasket. Attachment to the



1. Motor Dust Cap
2. Radial Fin
3. Conduit
4. Component Panel Mounting Block
5. Upper Flange
6. Electrical Lead
7. Housing
8. Keying Boss Tee
9. Lower Flange

Figure 11. Fan Assembly.

dust separator/airflow control valve assembly is made at the lower flange (9). The mounting blocks (4) along one side of the fan assembly casting provide the mounting surface for the component mounting panel. Tee-shaped projections (8) slide into mounting rails attached to the housing side wall. This mounting method retains the precleaner from transverse or longitudinal movement as well as helping to prevent damage to other precleaner components during installation and removal.

The characteristic curves of the fan assembly used in the E49 Filter Unit are shown in Figure 12. The static pressure curve is relatively steep and contains no reflex or saddle which would indicate areas of surge. The steepness of the curve aids airflow control in that relatively large changes in pressure correspond to small changes in flow.

At rated flow, 440 cfm, the fan motor turns at 11,000 rpm and draws 87 amps. Brake horsepower at rated flow is 2.3 hp.

The fan assembly is designed for a minimum operating life, operating in 0.025 gm/cu ft AC Coarse Test Dust, of 1000 hr. Minimum bearing and brush life are estimated at 500 hr. However, the result of reliability testing (Appendix D) indicate that 1000 hour maintenance of these items may be acceptable.

A feed-through capacitor mounted on the component mounting panel provides radio noise suppression for the fan motor. Noise in terms of both overall sound pressure level, OASPL, and the irritability measurement, PNdb, are below the level that is acoustically objectionable from the Human Factors Engineering standpoint[11].

F DUST SEPARATOR/AIRFLOW CONTROL VALVE

The dust separator/airflow control valve, Figure 13, serves the dual function of separating a minimum of 92 percent of dust from incoming air and providing a variable restriction to regulate air flow output from the fan assembly and thereby regulate crew compartment pressure. The two functions are combined in a single assembly only because of the physical construction of the precleaner.

The upper flange (4) mates with the downstream end of the fan assembly and is sealed with an O-ring. A ring of 14 dust separator tubes nests around the motor. This con-

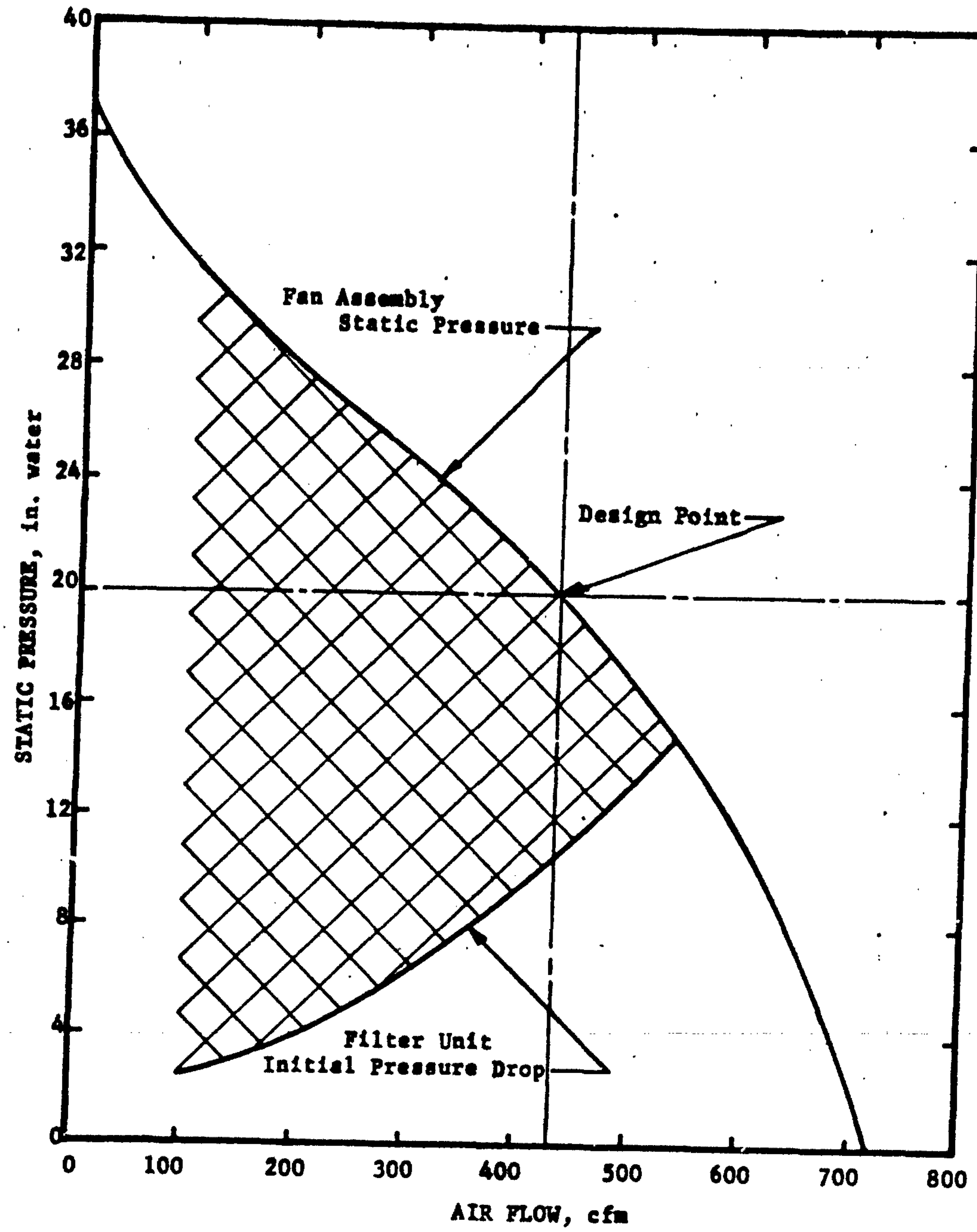
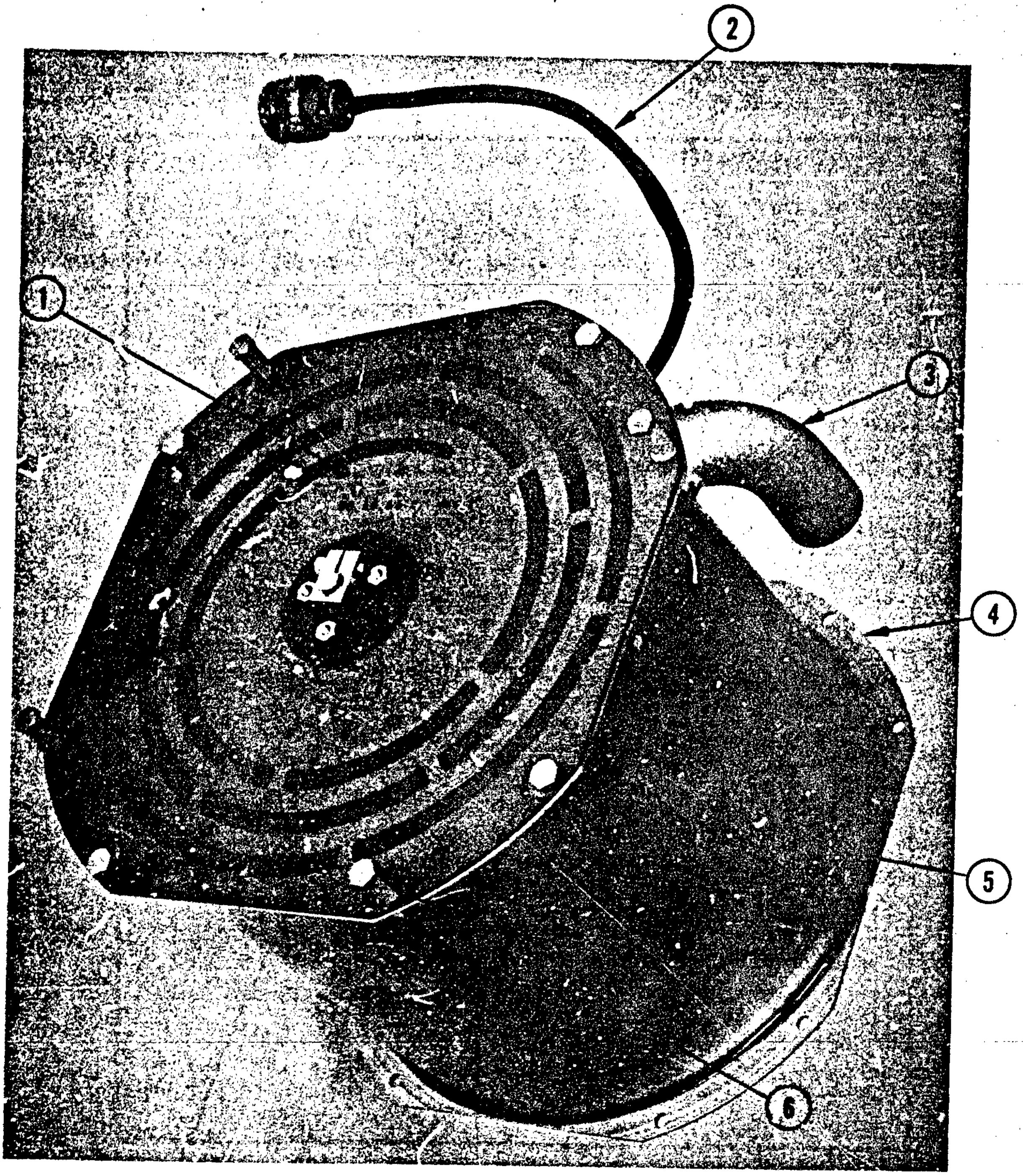


Figure 12. Fan Characteristic Curves.



1. Stationary Plate
2. Electrical Lead
3. Dust Exhaust Tube
4. Upper Flange
5. Dust Separator Housing
6. Leg

Figure 13. Dust Separator/Airflow Control Valve.

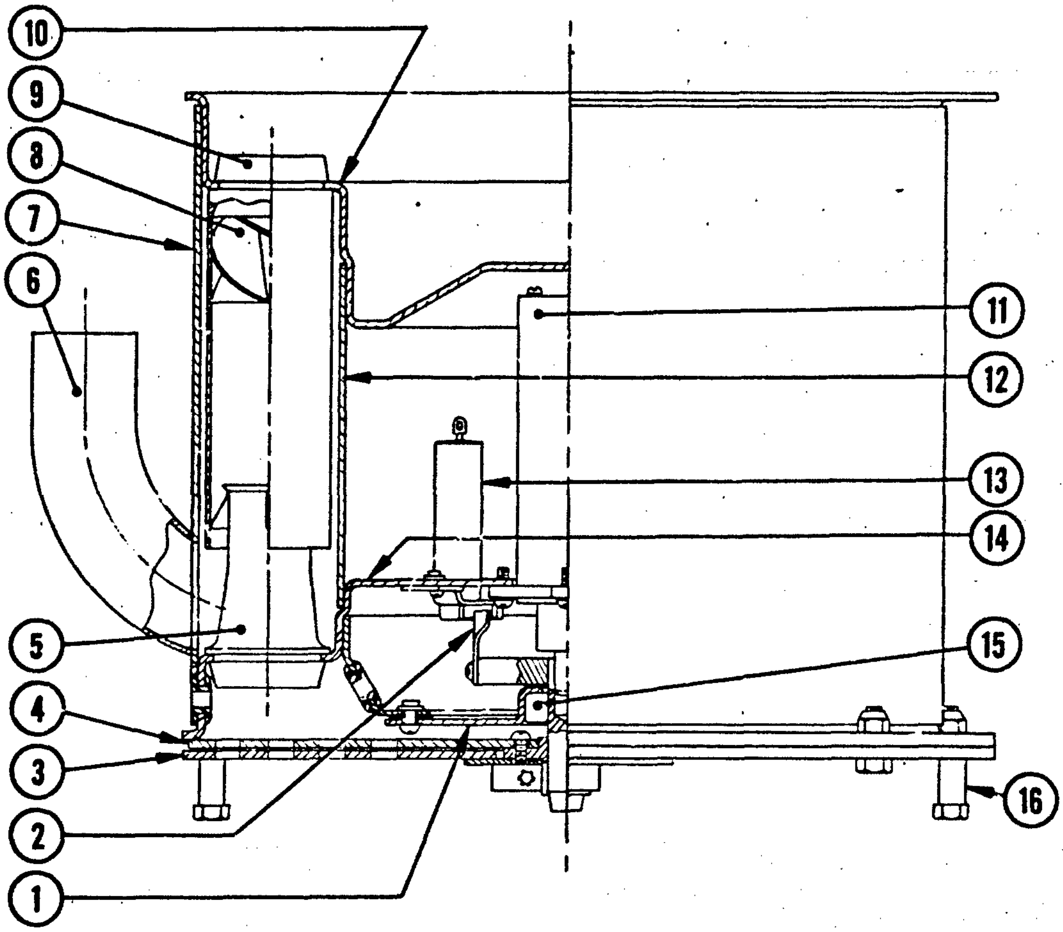
figuration makes optimum use of the outlet configuration of the fan assembly, combined with the shape of the separator tubes.

The cross-sectional drawing, Figure 14, more clearly illustrates the relationship of the various parts. Each of the 14 dust separator tubes consists of three parts - a body tube (9), helical vane (8), and outlet tube (5). The body tube presses into the upper baffle plate while the outlet tube presses into the lower baffle plate (14). The dust scavenging outlet duct (6) completes the items related to dust separation.

The dust separator operates as follows: Air containing contaminants enters the separator tubes and passes through the vanes, which impart a swirl to the air. Centrifugal force tends to separate the dust particles to the outer wall of the body tube. The middle core of air is then at a much lower dust concentration than the outer portion. As the air moves down the body tube, the relatively clean, inner core of air, passes through the outlet tube. The dust-laden air passes by the outlet tube and into a chamber, from which it is exhausted through the dust scavenging outlet duct. The inner baffle and the outer wall, in conjunction with the baffle plates to which the body tube and outlet rube mounte, serve to contain the collected dust from escaping, except through the scavenging duct.

The dust scavenging system consists of a 1.12-inch ID tube extending upward alongside the dust separator and fan assembly and projecting through the top cover casting of the precleaner. Tests were run to prove that the 18-inch rise from the dust separator to the cover did not cause problems of either carrying the exhausted dust out of the Filter Unit or reducing overall efficiency of the separator tubes. The velocity in the duct is approximately 100 ft/second which is sufficient to float a 500 micron dust particle. Tests were also run, alternating rain and dust (reference paragraph VI.A) which proved that this design would be effective when exposed to potential mud or sludge buildup.

The scavenging airflow exhausts the dust from the Filter Unit beneath the deep-fording valve cover. The dust is deflected by a plate so it exhausts outward, away from the inlet. Tests have shown that little or no recirculation of dust back into the inlet occurs with this design. The Filter Unit, as it was designed for the MBT, mounts in the engine compartment. In this location, air is drawn across the top of the Filter Unit by a radiator cooling



1. Drive Seal Baffle Plate
2. Limit Switch Actuator Arm
3. Fixed Flow Control Plate
4. Rotating Flow Control Plate
5. Separator Outlet Tube (14)
6. Dust Scavenging Outlet Duct
7. Outer Wall
8. Helical Vane (14)
9. Separator Body Tube (14)
10. Upper Separator Tube Baffle Plate
11. Drive Motor
12. Inner Baffle
13. Radio Noise Suppression Filter (2)
14. Lower Separator Tube Baffle Plate
15. Drive Shaft Seal
16. Legs

Figure 14. Dust Separator/Airflow Control Valve Assembly Cross-Section.

fan. The scavenging flow outlet is positioned so that this air flow over the Filter Unit draws the exhausted dust away from the inlet.

The airflow control valve attaches to the downstream end of the dust seperator/ airflow control valve assembly. The valve consists of two flat circular plates, each having a series of 5/16-inch wide slots which spiral inward in the form of a single start, double pitch spiral. When one plate rotates in relation to the other, the slots gradually close. A rotation of 180° cover the slots completely. This design causes approximately 1-inch pressure drop at 400 cfm.

The outside or lower plate (3) is fixed in relation to the outer body. Four spacers (16) extend downward to protect the airflow control valve assembly from damage when removed from the Filter Unit. The movable plate (4) is free to rotate within the dust separator shell.

Rotation is provided by a reversible dc drive motor (11). The motor is similar to that used in the deep-fording valve assembly. It produces 1000 in.-oz torque and draws 0.8 amp power. The drive motor mounts on the same baffle plate used to retain the dust separator tubes. Radio frequency emmissions from the drive motor are filtered out by two noise suppression filters. A seal (15) is provided in a secondary baffle plate (1) for the drive motor shaft to prevent dust from reaching the electrical connections to the drive motor and limit switches. The seal contains silicone impregnated leather to provide a lubricated bearing surface against the drive shaft.

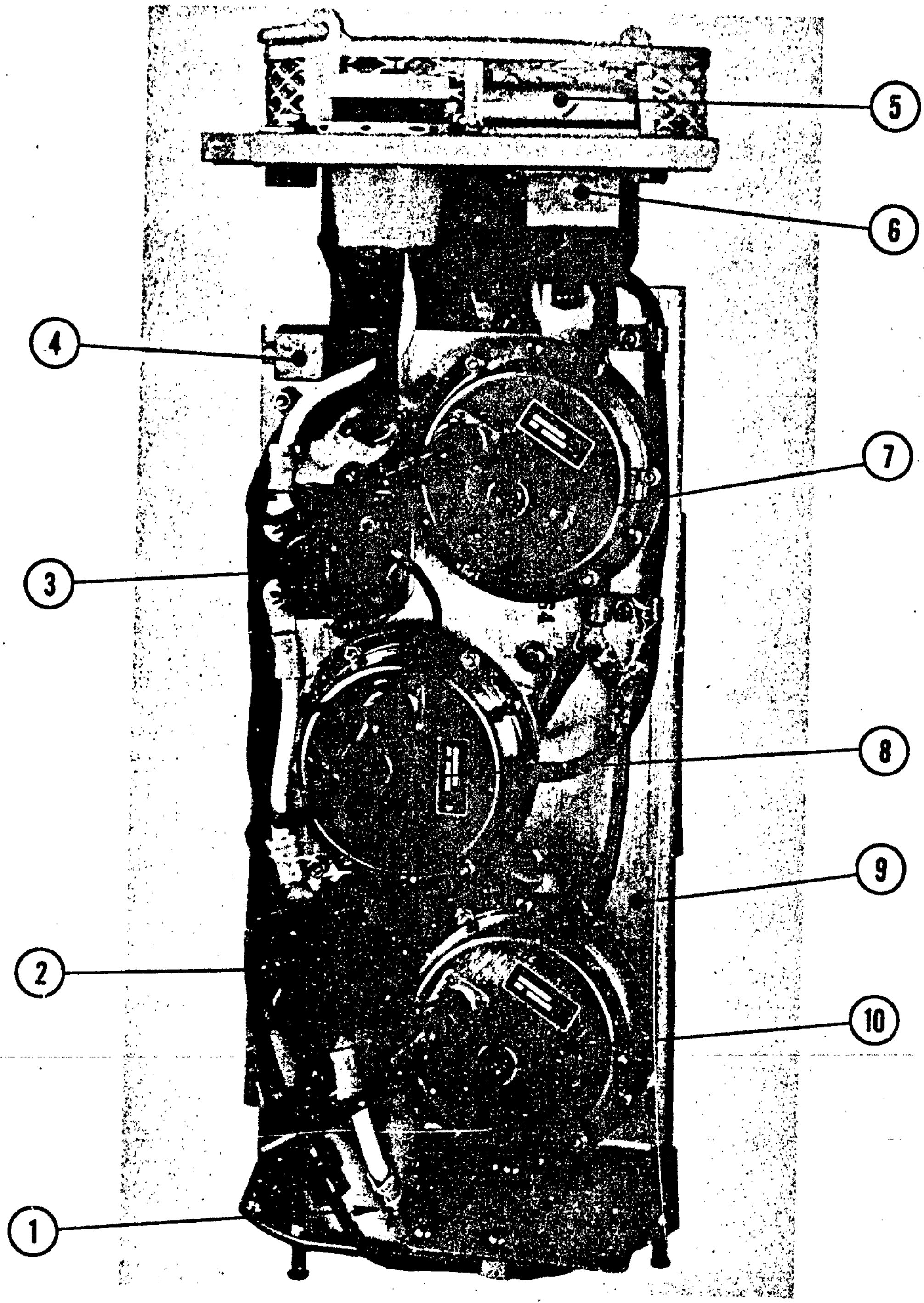
Limit switches keep rotation of the plate within its prescribed limits. The limit switch actuator arm connects to the drive shaft.

The plates of the airflow control valve are in sliding contact with each other. This sliding action automatically scrapes off any collected dust or mud which might build up. To assure minimum friction between the plates, each plate has a hard anodic coating per AMS 2469[12] to harden the surfaces as well as a solid film lubricant coating, per MIL-L-25504[13], to reduce the coefficient of friction.

G COMPONENT MOUNTING PANEL

The component mounting panel, Figure 15, provides a convenient mounting panel for the various electrical and pneumatic components of the Filter Unit. The panel mounts to the fan assembly housing.

The power relay functions as the contactor for the fan motor. This relay is rated at 100 amp dc. The fan motor overload relay (2) provides protection to the fan motor from ex-



1. Feed-Through Capacitor
2. Fan Motor Overload Relay
3. Power Relay
4. Limit Switch Relay
5. Precleaner Cover
6. Pressure Manifold
7. High Pressure Switch
8. Low Pressure Switch
9. Component Panel
10. Filter Restriction Switch

Figure 15. Component Mounting Panel (Precleaner).

cessive current draw. The device is not rated for operation down to $-65^{o}F$ as required; however, it comes closest to meeting the wide operating temperature range of any known protector and has been approved by ATAC for operation at $-40^{o}F$. A small relay (4) provides an additional set of contacts for the low pressure switch. The relay was necessary since no pressure switch is available which contains a 3PDT switch. This relay is a plug-in type. The contactor part of the relay can be removed without disturbing the wires. The small tubular filter (1) provides radio suppression for the fan assembly motor. This noise filter is a 10 mf feed-through capacitor.

The three 5.25-inch diameter diaphragm-type pressure switches are mounted in a vertical arrangement. The upper two pressure switches (7, 8) provide the upper and lower control points for crew compartment pressure. The lower pressure switch (10) monitors pressure drop across the filter.

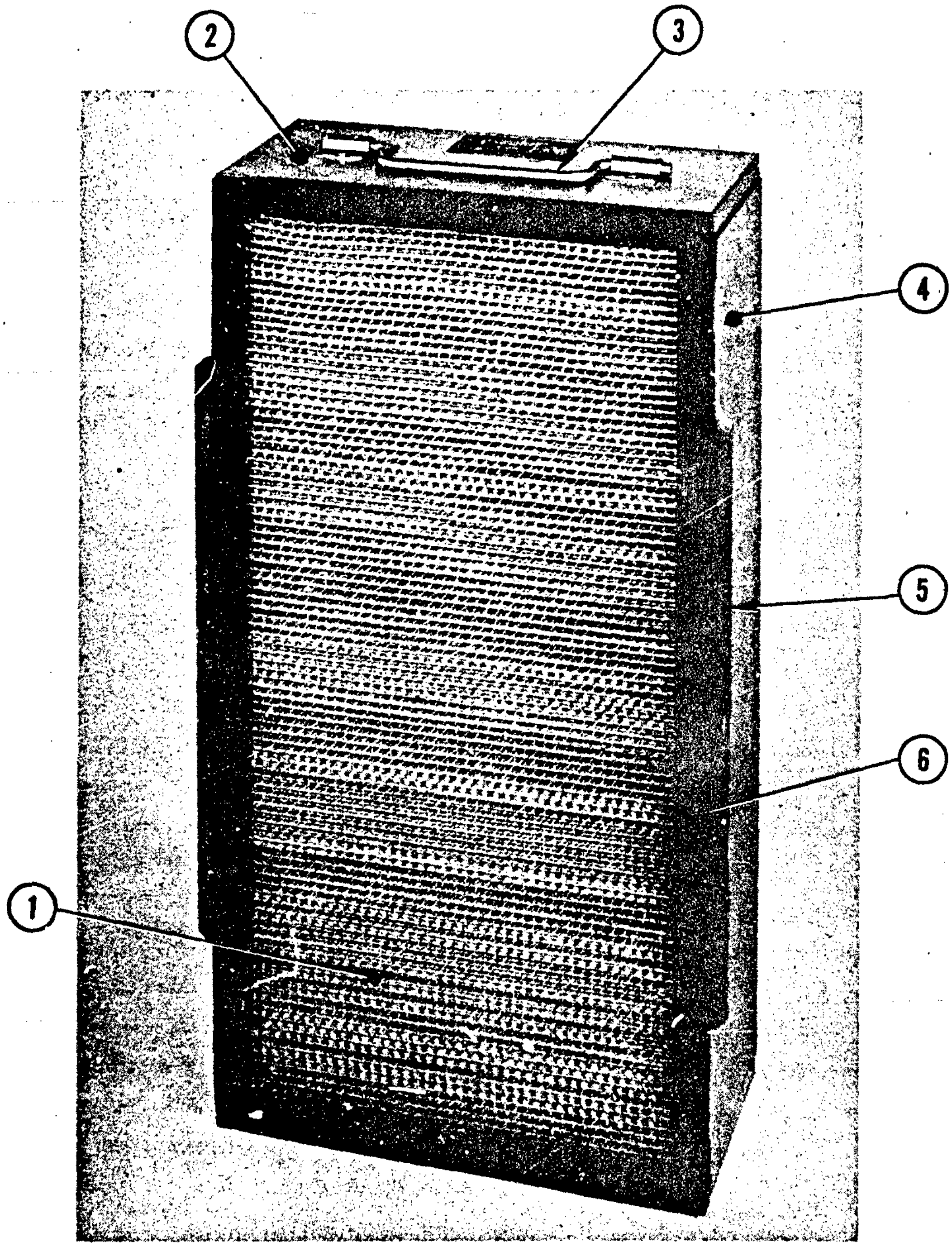
AN type connectors are provided to facilitate removal of certain electrical components for maintenance and repair.

The entire component mounting panel is removable from the precleaner by removing four bolts screwed into the fan assembly and disconnecting three AN connectors.

H FILTER, PARTICULATE, 400 CFM, E59

The particulate filter developed for the E49 Filter Unit is illustrated in Figure 16. The filter has outside dimensions of 12.75 in. wide x 24.75 in. high x 5.75 in. deep. It contains particulate media having 88 sq ft of effective area, separated by diagonally corrugated aluminum pleat spacers (1). Pleat depth is 5.25 in. Using 3/32 in. deep corrugated spacers, 101 pleats on each side (202 pleats both sides) can be included in the filter. Because of corrugated spacer height variations, the tolerance in number of pleats is about 2 percent. The media velocity at rated flow, 400 cfm, is 5 ft/min while approach velocity to the 23.44 in. x 11.25 in. open face area is 220 ft/min. Each filter face is covered with 4 x 4 x 23 gauge screen. This screen helps protect the delicate media from damage in handling. The media, spacers and screen seal to the aluminum end caps (2) and side channels (4) with plastisol. The inside of the frame is coated with primer before assembly, to assure the required bond to the plastisol. The plastisol endseal material meets MIL-E-51065[7].

Each side channel is spot welded to a 3/32-inch thick aluminum sheet containing an outward-turned lip (5), forming a pressure angle which fits into the filter retaining mechanism. This lipped sheet extends back across the depth of the filter to provide additional strength and facilitates plastisol curing.



1. Filter Media
2. End Cap (2)
3. Handle
4. Side Channel (2)
5. Pressure Angle (2)
6. Gasket

Figure 16. Filter, Particulate, 400 cfm, E59.

A handle (3) is screwed to the top for convenience in handling the filter. This handle lies against the filter top, as shown, when installed in the Filter Unit.

A solid molded gasket (6) is attached to the downstream side of the filter. This gasket is natural foam rubber coated with a 3 mil thick neoprene film. Its load deflection rate is 9 ± 4 psi at 25 percent compression.

I FILTER, GAS, 400 CFM

1 Vertical Gas Filter, E61

Figure 17 illustrates the gas filter supplied with the E49 Filter Unit. This filter has outside dimensions of 24.75 in. high x 12.75 in. wide x 12.0 in. deep. The framework is constructed of 5052H34 aluminum alloy. The filled pack weighs approximately 96 lb. Two handles (4) are attached to the top cover (5). The cover is screwed to the pack after filling is complete. When installed in the Filter Unit, the pressure angles (7) on each side fit into the channels of the retaining mechanism attached to the housing wall. The gasket (3) seals against the downstream fail-safe sealing channel attached to the end of the housing. This gasket is a solid, molded natural sponge rubber having a 3-mil thick neoprene coating. As with the particulate filter gasket, the load deflection rate is 9 ± 4 psi, at 25 percent compression.

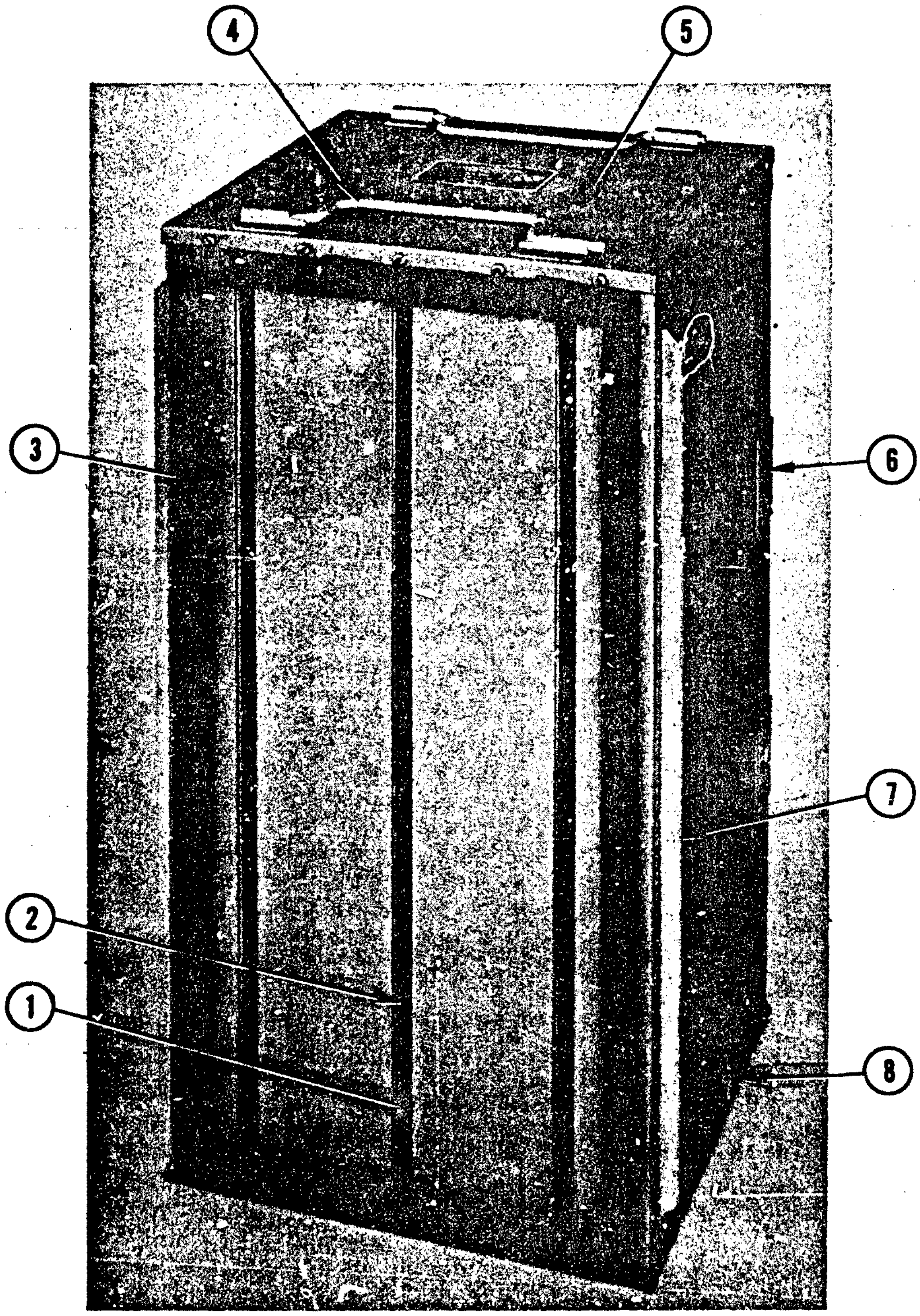
Within the gasketed area, three vertical outlet air chambers (1) are visible. The corrugated spacers (2) which prevent bowing of the perforated metal are also visible. These spacers slide into the chamber in a force fit.

To retain the gas filter in the housing under shock conditions, pads (8) are welded to the bottom and center of each side. An arm, extending from the filter retaining mechanism in the housing, slides over each pad to prevent vertical movement. To prevent lateral movement, additional shock pads (6) are spot welded to the sides, near the upstream end, to mate with similar protrusions on the housing walls.

The charcoal is retained by 0.063 inch thick aluminum perforated metal, with 100 straight pattern holes of 0.065-inch diameter per sq in. Cotton fines retaining media per MIL-C-299[24] is glued to the inside of the perforated metal to prevent fine particles of charcoal from passing through the holes.

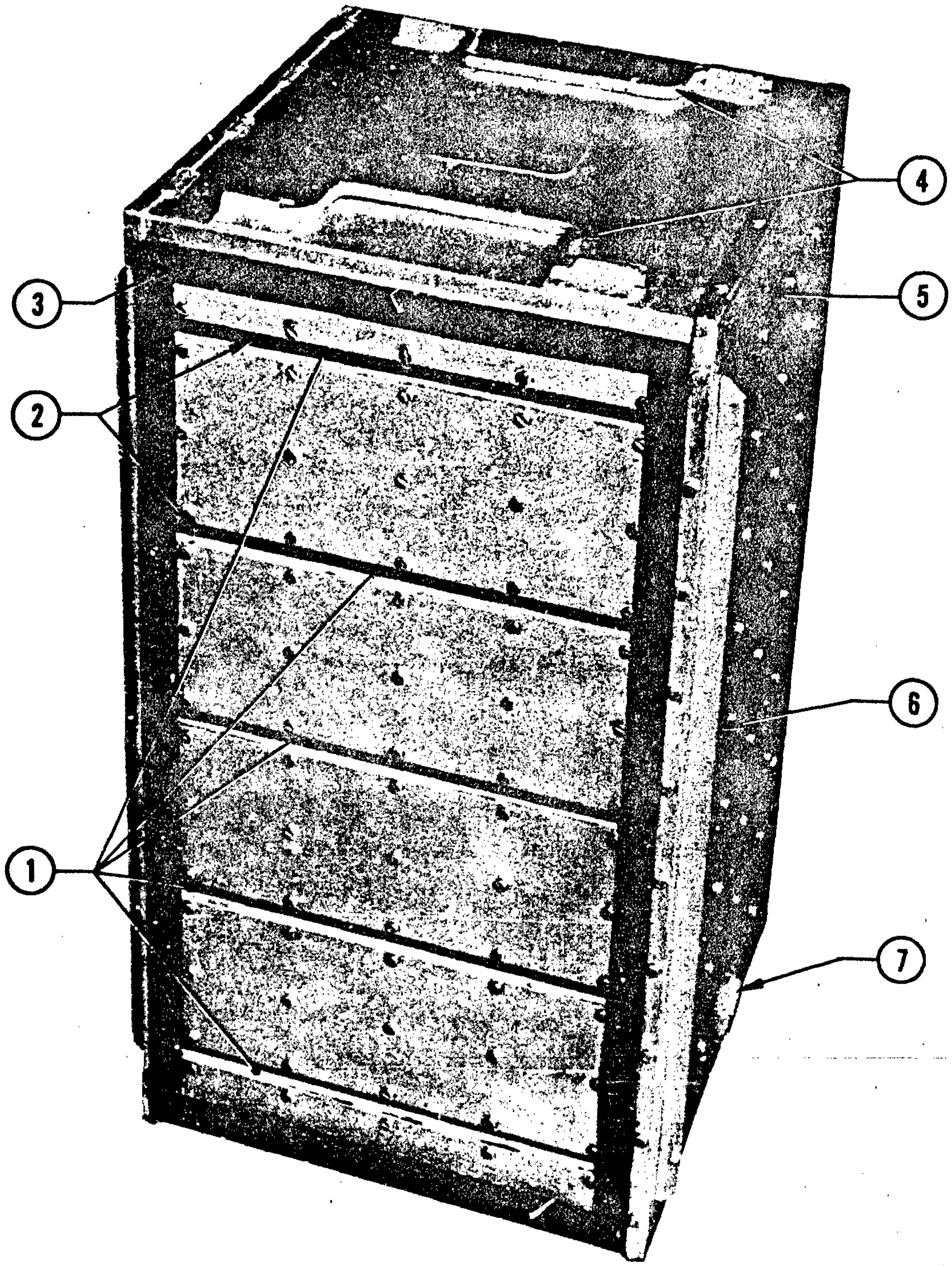
2 Horizontal Gas Filter, E60

The unitized gas pack concept was also used for an alternate design gas filter. This alternate design, which is directly interchangeable with E61 Gas Filter, is shown in Figure 18. It has the same outside dimensions, handles and gaskets as the E61 filter.



1. Air Exit Chamber (3)
2. Air Chamber Spacer
3. Gasket
4. Handle (2)
5. Cover
6. Lateral Shock Pad (4)
7. Pressure Angle (2)
8. Vertical Shock Pad (2)

Figure 17. Filter, Gas, 400 cfm, E61.



1. Air Exit Chambers
2. Air Chamber Spacers
3. Gasket
4. Handles (2)
5. Side Plate
6. Pressure Angles (2)
7. Vertical Shock Pads (2)

Figure 18. Filter, Gas, 400 cfm, E60.

The horizontal gas filter contains 10 charcoal beds separated by air chambers. As with the vertical gas filter, the air chambers (1) are kept from bowing by corrugated spacers (2) pressed into each air chamber. Charcoal is retained by the same perforated metal and cotton fines retaining media used in the E61 gas filter. The horizontal gas filter is filled from the side (5) whereas the vertical gas filter is filled from the top.

The photo of the horizontal gas filter shows that a considerable number of sheet metal screws are required to retain the air chambers. The vertical E61 gas filter has been taken further in development and contains extrusions spot welded inside the gas filter walls to allow the air chambers to slide in and eliminates the need for screws.

Vibration tests of the vertical and horizontal design filters were performed to determine the advantages of one or the other. The test results showed that the E61 gas filter was distinctly superior, since the charcoal could be mechanically restricted; minimizing movement of the charcoal and slowing down the processes which cause filter failure in a vibratory environment. Also, since the E61 filter is easier to fabricate, both in charcoal filling and mechanical assembly of the filter shell, the E61 filter was selected for the E49 Filter Unit.

J HOUSING

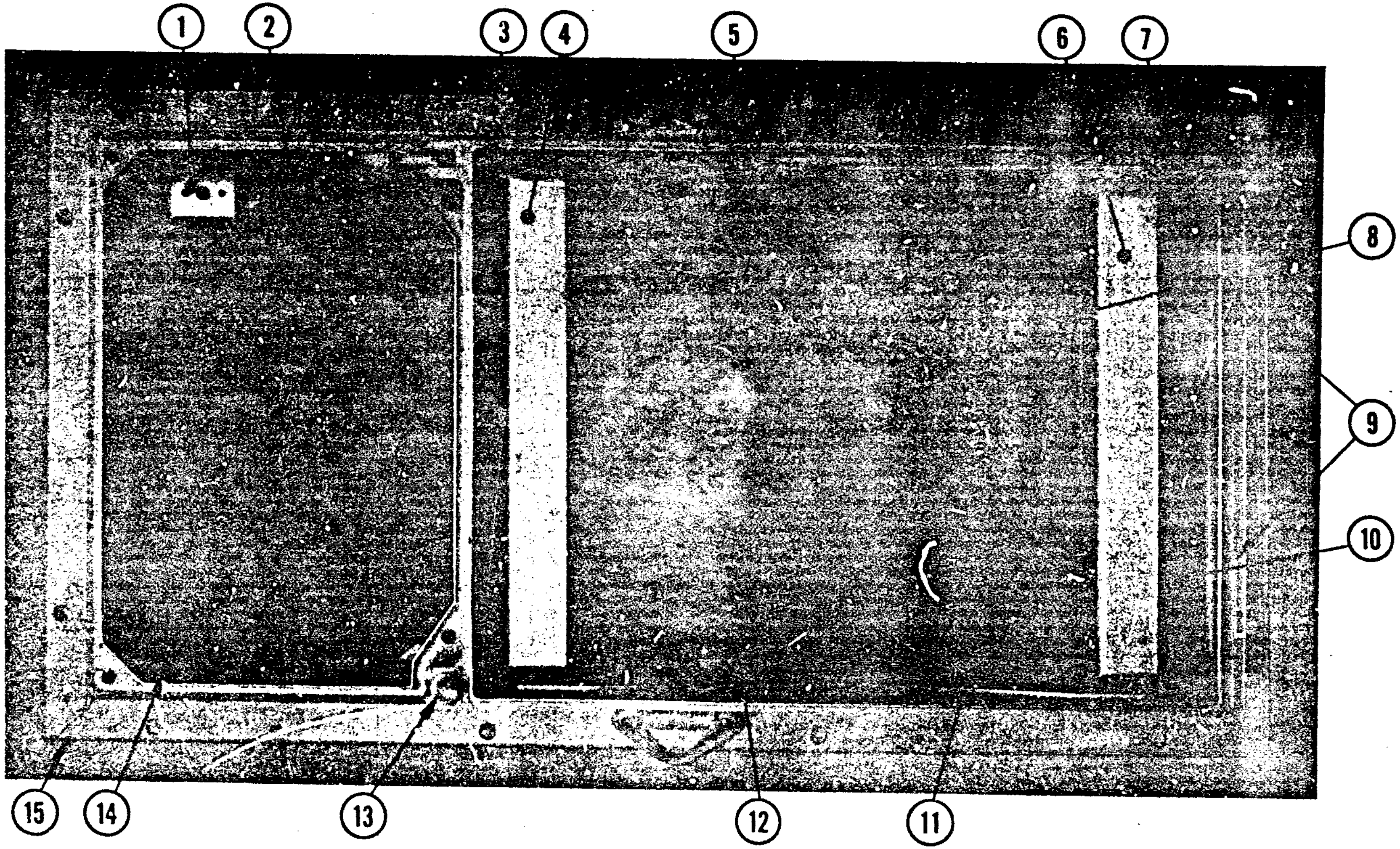
1 General

The housing for the E49 Filter Unit is illustrated in Figure 19. This photograph shows all significant parts within the housing. The side wall material is 3/16-inch thick 5052H34 aluminum alloy. Except for minor parts, the remaining pieces welded to the aluminum box are also of this material. The housing is of welded construction, utilizing both resistance and arc welding methods.

After completion of the housing weldment, the entire weldment is irridited for corrosion resistance. Then, after priming, the outside is painted with No. 24533 light green paint per TT-E-529[14].

The left hand portion of the housing contains the precleaner. The two slotted rails (14) welded to the side wall retain the precleaner from transverse and longitudinal movement.

The lower half of the tubing manifold (1) is mounted on the opposite wall from the precleaner mounting rails. The upper half of this manifold mounts on the precleaner cover. This manifold forms a quick disconnect for the fail-safe sealing tubes and pressure tubes (2). It allows the precleaner to be removed from the housing without removing any tub-



1. Tubing Manifold, Lower Half
2. Pressure Tubing
3. Particulate Filter Fail-Safe Sealing Channel
4. Particulate Filter Retaining Mechanism Handle
5. Gas Filter Shock Pads (2)
6. Gas Filter Retaining Mechanism Handle
7. Gas Filter Fail-Safe Sealing Channel
8. Filter Unit Outlet
9. Filter Access Cover Hinge Slots
10. Press-nuts (16)
11. Crew Compartment Pressure Tap
12. Tubing Shield
13. Filter Access Cover Swing Bolt (2)
14. Precleaner Mounting Rails (2)
15. Mounting Flange

Figure 19. Filter Unit Housing.

ing from its connector. The manifold consists of a pair of aluminum blocks with matching holes to allow pressure to pass from one half to the other. Sealing between the halves is accomplished by a solid rubber gasket. The lower half of the manifold floats vertically, guided by two pins. This prevents alignment problems when drawing the two halves together with the bolt which extends down through the precleaner cover and upper manifold half.

The right-hand section of the housing contains the particulate and gas filters. The inlet to this portion is a rectangular opening 20.2 in. x 10.6 in. The outlet of the filter unit (8) is the 8 in. x 13.25 in. rectangular opening at the downstream end. In the MBT application, the outlet is designed to attach to the Environmental Control Unit. For use in other applications, either a diffuser or other ducting is easily adaptable to this outlet. Two gas filter shock pad points (5), mounted on each housing side, match the pads welded to the gas filter. These retain the gas filter from lateral movement.

2 Fail-safe Filter Sealing

Fail-safe filter sealing channels (3, 7) seal against the gaskets of the particulate and gas filters. These channels increase the reliability of sealing by providing a redundant sealing surface. Even though the particulate or gas filters themselves are capable of giving the prescribed protection, their effectiveness is reduced with inadequate sealing. Thus, it is imperative that a reliable method of sealing the critical joints be provided.

The particulate filter and gas filter gaskets seal across both lips of a U-shaped channel and create a closed volume within the channel. This internal volume is connected with rubber tubing to the inlet of the fan assembly. At the fan assembly, the pressure is slightly below atmospheric pressure. Thus, the internal volume of the channel is at a pressure lower than atmospheric pressure.

The pressure produced by the fan assembly is progressively reduced across the Filter Unit components, such as the particulate filter and gas filter, until approximately 1-in. water pressurization remains in the crew compartment. The pressure upstream of the particulate filter is higher than the pressure downstream of the gas filter. Thus, if the particulate filter were not adequately sealed at its upstream gasket, leaks would tend to bypass the particulate filter. A similar situation exists with the gas filter. By providing the channel under negative pressure, any leaks past the gasket will travel through the rubber tubing and back into the inlet of the fan assembly. From this point the air is again recirculated and purified.

Pressure tubes (2) which extend from the tubing manifold are fail-safe tubes for the particulate filter and gas filter channels as well as the crew compartment pressure tap (11) tube.

In addition to the sealing surfaces provided for the particulate and gas filters, sealing surfaces are required around the top of the housing for the filter access cover and precleaner cover seals. The housing top contains a 1/8-inch wide projection which mates with the gasket on each cover. This allows a small area, high force seal around the periphery of both the precleaner portion and the filter portion of the housing. Potential leaks at these joints are fail-safe since, if leaks occur, they will be back to atmosphere.

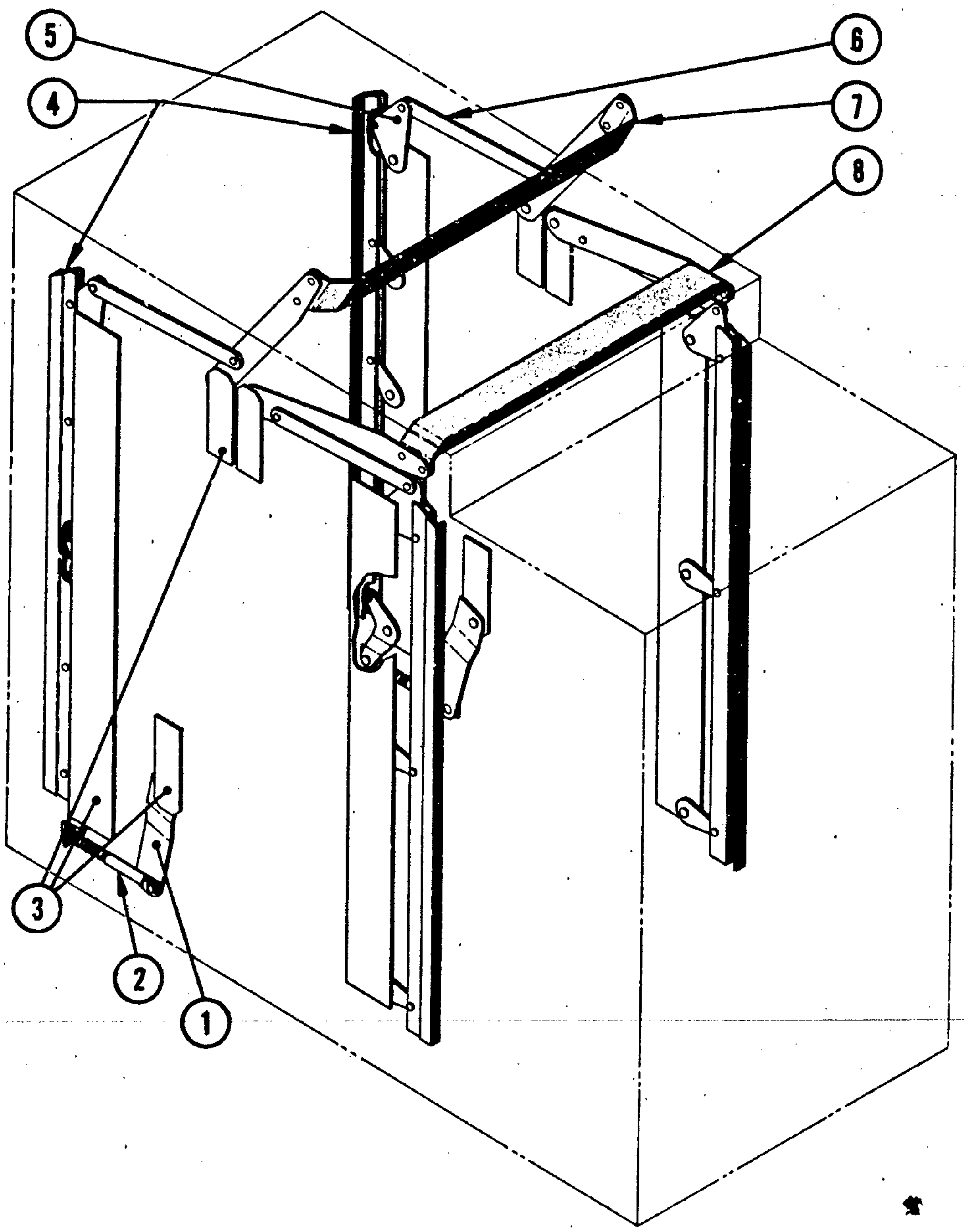
3 Filter Retaining Mechanism

The filter retaining mechanisms, Figure 20, provide reliable filter sealing while giving maximum ease of filter servicing. Operation of this mechanism depends upon the action of mechanical linkages which force the respective filters against their sealing channels.

Each mechanism is composed of two halves, tied together with handles (7, 8) extending over the top. The handles are mechanically linked to pressure bars (4) by the pivot plate (5) and linkage (6) on each side. The pressure bars are extrusions with an inward-facing channel. The channels are designed to accept the pressure angles of the respective filters. When the handle is swung downward, the mechanical links move the pressure ba longitudinally carrying the filter against its sealing channel. To reduce the possibility of galling the filter pressure angle with the retaining mechanism pressure bar, the latter contains a hard anodic coating per AMS 2469[12] and a solid film lubricant per MIL-L-25504[13] like that used on the plates of the airflow control valve assembly.

The retaining mechanism of the gas filter also contains a vertical shock retaining arm (1) on each side. The arms extend over the shock pads on the gas filter when the retaining mechanism is in its closed position. This prevents vertical movement of the gas filter under shock and vibration conditions. The various linkages are designed so that, in the sealed position, the mechanism has traveled slightly over-center. Thus, there is no tendency to spring open.

The respective placement of the pressure angles on the filter and pressure bars of the retaining mechanism prevents the possibility of interchanging the filters. The gas filters have their pressure angles further back from the gasket than does the particulate filter. Thus, the gas filter will not fit into the particulate filter retaining mechanism. The particulate filter will fit into the gas filter retaining mechanism; however, it will not mate against the sealing channel. Also, if the particulate filter is in the wrong position, the gas filter cannot be installed.



1. Shock Arm
2. Spring-loaded Shock Arm Link (2)
3. Mounting Pads (welded to housing)
4. Pressure Bars
5. Pivot Plate
6. Handle/Pressure Bar Linkage
7. Gas Filter Retaining Mechanism Handle
8. Particulate Filter Retaining Mechanism Handle

Figure 20. Filter Retaining Mechanisms.

4 Covers

The filter section of the housing is covered with a cast aluminum filter access cover. The inside of the cover has an egg crate pattern to provide adequate strength to withstand a 24 ft water fording pressure. Relieved areas allow room for the retaining mechanism and filter handles. The top side of this casting is smooth. The cover material is 356T6 aluminum.

The filter access cover attaches to the housing by two tabs on one end and two yokes on the other. The tabs fit into slots on the downstream end of the filter housing. This provides a simple hinge, allowing rapid removal of the cover from the Filter Unit. The other end of the filter access cover is retained by two swing bolts attached to the housing. These swing bolts fit into the slotted yokes cast onto the filter cover. The cover is drawn down against the housing by tightening two hex nuts on the swing bolts.

The filter access cover gasket is solid molded natural sponge rubber encased in a 3-mil thick neoprene film. The gasket mounts within the recess provided around the filter cover periphery.

The cast aluminum precleaner cover attaches to the housing with four bolts. The lower side of the casting also contains a recess-mounted molded sponge rubber gasket, similar to that used on the filter access cover.

K CONTROL PANEL, E67

Two different control panel designs were used with the E49 Filter Unit. The early, or Class II, version was designed to operate the Filter Unit during early phases of development and testing when changes were being made in the Filter Unit design. This panel was not designed to meet environmental requirements of the contract.

The final, or Class I, version of the control panel was designed to meet the requirements of the Filter Unit.

The Class II control panel had dimensions of 6.25 x 15 x 5.25 inches. A removable front plate was held in place by three screws. All components were mounted on this plate.

Square lighted pusbutton switches were used for system control in conjunction with round indicators.

The panel face was divided into three sections; power, crew compartment pressure, and service. The power section contained a toggle switch used as a main power switch,

and two lighted pushbuttons controlling the UNIT ON and UNIT OFF functions.

The crew compartment section contained the NORMAL and LOW PRESSURE indicator lights and the NORMAL/FIRING MODE switch. A WARNING HORN OFF switch was also included in this section.

The service section of the face plate contained circuit breakers, a filter restriction indicator, a lamp test switch, and an hourmeter.

The assembled panel weighed approximately 7 pounds.

Design logic for the Class I control panel, Figure 21, was agreed upon through coordination with representatives of CRDL, ATAC, and Human Engineering Laboratories at Aberdeen Proving Grounds.

Two control panel mockups were built to determine the best arrangement of components. The suggested layout presented by CRDL, had approximate dimensions of 6-inches x 10-inches x 6-3/4-inches, or a total of 405 cubic inches. The second model which was arrived at through rearrangement of panel components, was approximately 5-1/4-inches x 11-1/4-inches x 6-1/4 inches, or a total of 369 cubic inches. This compared with the earlier control panel design which had dimensions of approximately 6.25-inches x 15-inches x 5.25-inches, or 492 cubic inches. The optimum design panel has dimensions of 5-inches high x 11.4-inches wide x 6-inches deep, or approximately 341 cubic inches.

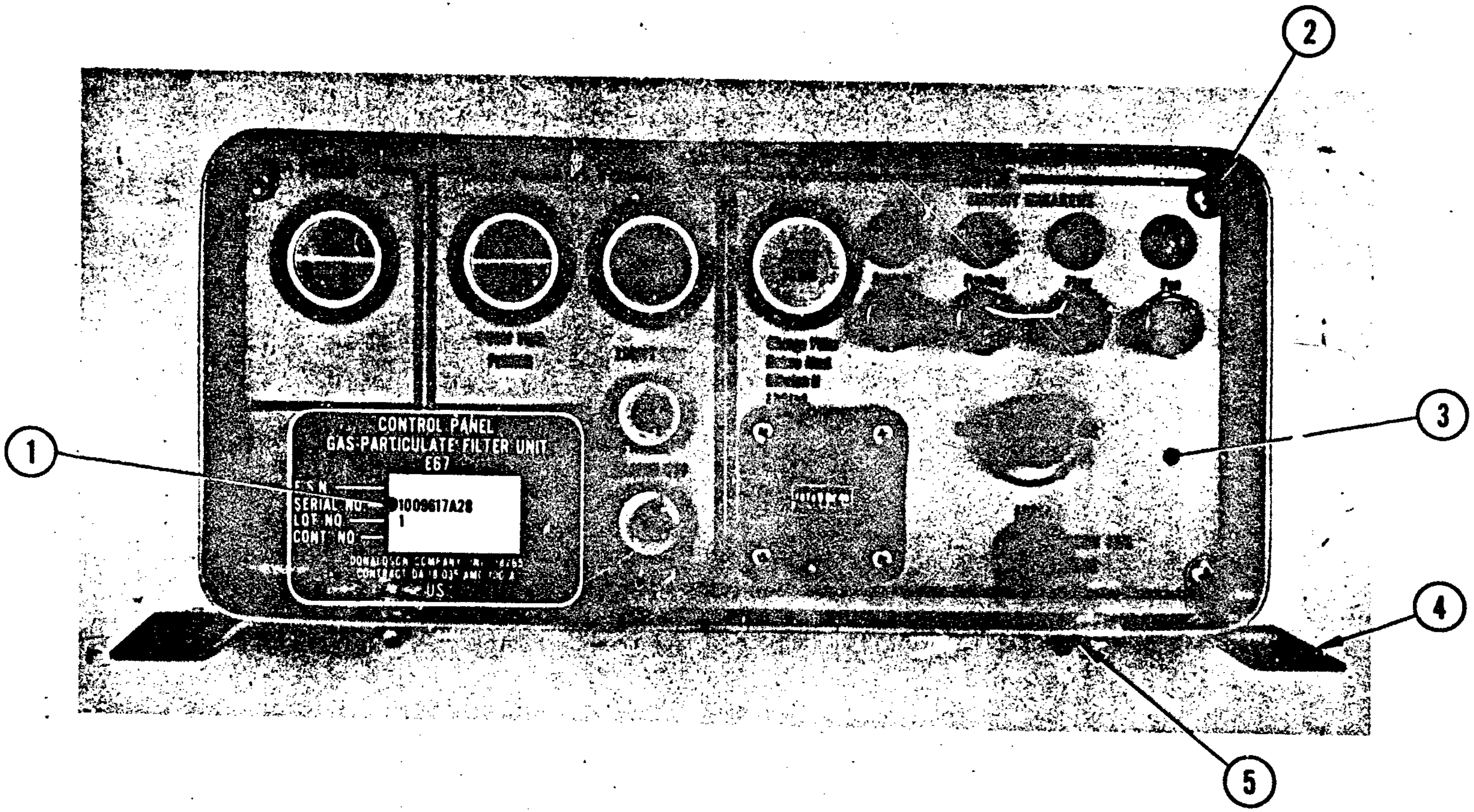
ATAC recommended use of round, lighted pushbutton switches, with a press-to-test/dimming switch for control panel indicators.

The use of a Mercury type hourmeter rather than the electro-mechanical type was considered. The price and size of the Mercury type hourmeter was very attractive, however, the readability was not as good and it would not operate below -45°F. Since the contract specified low temperature operation, and at the recommendation of ATAC, it was decided to use a digital electro-mechanical type hourmeter.

The following paragraphs describe the various design aspects of the control panel.

1 Power Section

The power section of the control panel contains only the UNIT ON switch. This is a split-screen, lighted pushbutton switch. The top half reads UNIT ON and lights green when there is power to the system and the fan is operating. If the system circuit opens, the UNIT ON portion of the switch lights red. The bottom half of the screen reads DO NOT FORD and lights amber when the deep-fording valve is open. This switch opens and closes



1. Spare Bulb Holder
2. Face Plate Mounting Screw (4)
3. Face Plate
4. Mounting Flange
5. Flange Retainer

Figure 21. Control Panel, Gas-Particulate Filter Unit, E67.

the deep-fording valve and activates all other control panel lights. It also indicates if the fan is on and if the deep-fording valve is open.

2 Compartment Pressure Section

The compartment pressure section of the control panel contains a low pressure indicator, LIGHT OFF and ALARM OFF pushbutton switches, and a manual override switch for firing mode operation.

The firing mode switch is a split-screen, lighted pushbutton. The top half reads FIRING MODE and the bottom half reads NOT MAX FLOW. When this switch is depressed, the FIRING MODE lights green and the bottom half of the switch does not light. This switch overrides the automatic pressure sensing system and delivers the maximum amount of air available from the Filter Unit. When the switch is in this mode and a malfunction occurs which prevents the airflow control valve from going to the open position, the entire screen lights amber. It is proposed that eventually the firing mode will have both manual and automatic controls. However, with the current status of the MBT and its weapons system, automatic operation provisions were not incorporated.

There is a red flashing light with an inscribed MASK to indicate low crew compartment pressure, as well as an audible alarm. The flasher for the MASK light is mounted on the rear of the panel face and is fail-safe. If the flasher fails, the warning lamps will light continuously during low pressure conditions.

The panel has both a LIGHT OFF and an ALARM OFF switch. The LIGHT OFF switch turns off the flashing red low pressure warning light. The ALARM OFF switch turns off the audible alarm system. Both of these switches are automatically reset when crew compartment pressure normalizes.

3 Service Section

The service section of the control panel contains a particulate filter servicing indicator, an hourmeter, a lamp test switch, indicator dimming switch, and four circuit breakers with indicator lights.

An amber light inscribed CHANGE FILTER indicates required servicing of the particulate filter.

The hourmeter indicates the actual hours of Filter Unit operation and may be used for maintenance scheduling of the fan assembly.

There is a system circuit breaker with a red light to indicate when the system circuit is open. In addition, the UNIT ON indicator lights red if the system circuit breaker is open. There is also a circuit breaker with an amber light to protect the deep-fording valve motor, one with an amber light to protect the flow control motor, and a switch with an amber light to remotely reset the fan overload. The indicator lamp test switch can be depressed to test all lamps in the control panel. A dimmer switch contains a rheostat for dimming all panel lights, except the red warning lights.

4 General Panel Design

The face of the control panel is recessed approximately 0.5-inch to protect switches and lights. A gasket is used to seal around the panel face making the box dust and splash proof.

All components are mounted on the face of the panel. A quick disconnect connector is provided for easy removal of the face in the event of major repair.

A name plate is located on the face of the panel with spare lamps located behind the plate. Since repair lamps are located on the face, it was not necessary to hinge the panel face and it is therefore bolted on. A mounting bracket is bolted to the bottom of the control box. This bracket may be removed and replaced with any required mounting depending on application.

L CONTROL CIRCUITRY AND OPERATION

1 General

The Filter Unit uses both pneumatic and electrical components for control functions. The pneumatic system consists of three pressure switches and related tubing which monitor differential pressure across the particulate and gas filters and monitor pressure between atmosphere and the Filter Unit outlet which corresponds to crew compartment pressure. Filter pressure drop is indicated on the control panel if it becomes too high. The two switches monitoring crew compartment pressure and atmospheric pressure control the electrically operated airflow control valve, which in turn varies the airflow to maintain the crew compartment pressure.

The electrical components consist of the fan motor, deep-fording valve drive motor, airflow control valve drive motor, along with switches, indicators and associated parts. The entire electrical system operates on 27.5 ± 0.5 vdc, supplied by the vehicle electrical system.

No pneumatic, hydraulic or other power is required from the vehicle. Electrical input to the Filter Unit is through an AN connector attached to the precleaner cover. This same connector provides the connection to the control panel, which mounts within the crew compartment.

The control circuitry is concentrated in two areas of the Filter Unit; in the control panel and on the component mounting panel within the precleaner.

2 Filter Unit Operation

a. Start Up

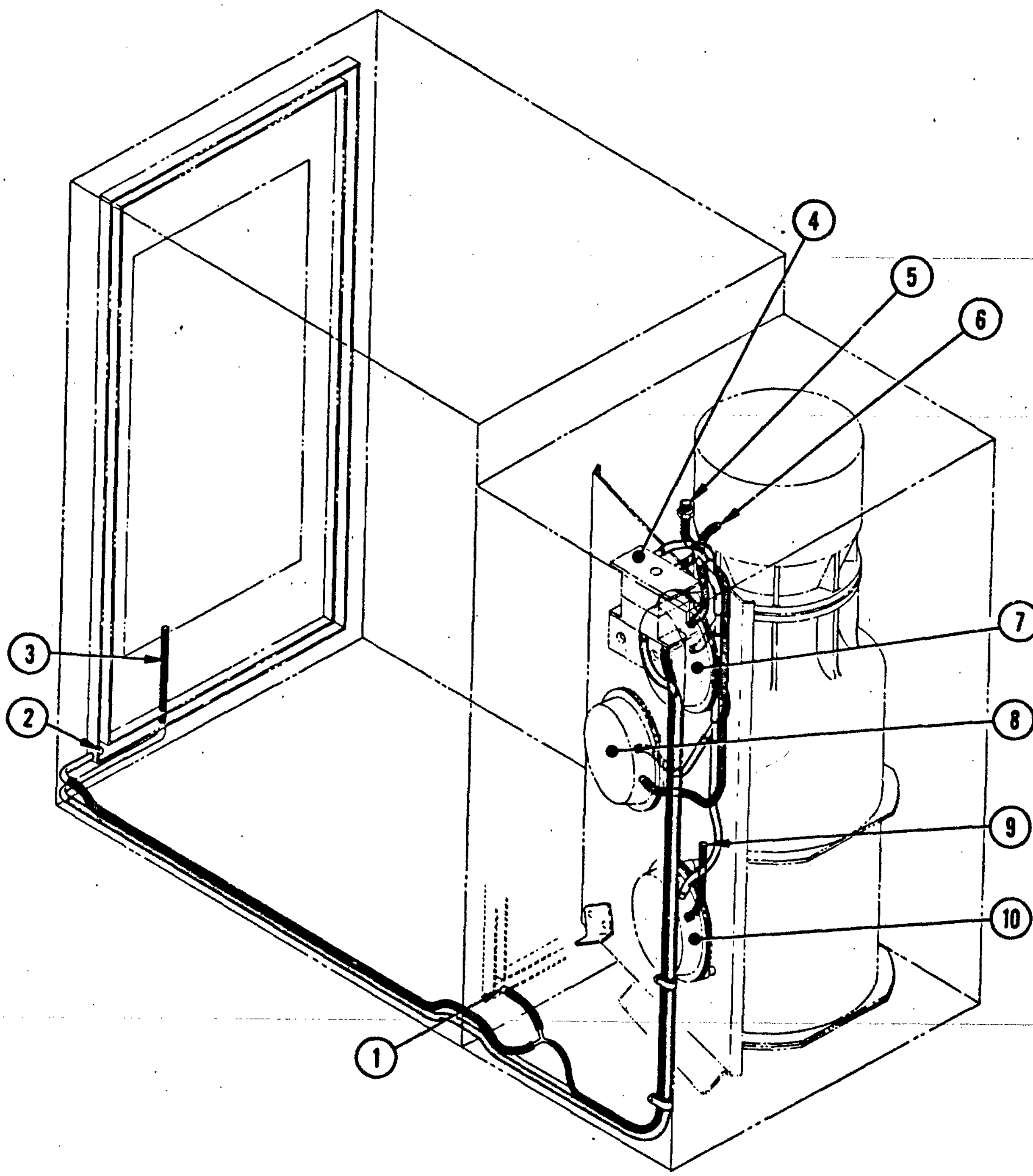
The Filter Unit is started by depressing the UNIT ON/DO NOT FORD switch on the control panel. This applies power to the fording valve drive motor, causing the cover to open. Power is also applied to the fan motor power relay, through an interlock circuit in the deep-fording valve that prevents fan operation until the valve is open. When the fording valve reaches its open position, the fan motor power relay energizes, completing the circuit to the fan motor through the motor overload protector and a radio frequency noise suppressor.

The fan starts, drawing air from the inlet and discharging through the dust separator/airflow control valve assembly, particulate and gas filters and on to the ECU and/or crew compartment. To keep outside air from entering the crew compartment through leaks, the air pressure in the crew compartment must be maintained above atmospheric pressure. The system of pressure switches and electrical components automatically regulates the airflow to obtain the necessary pressurization.

b. Crew Compartment Pressure

The system that regulates crew compartment pressure consists of a motor driven airflow control valve, two pressure switches, and the necessary pressure taps and tubing. A pressure tap at the outlet of the Filter Unit senses crew compartment pressure. Another tap at the air inlet, beneath the fording seal cover, senses atmospheric pressure. These are shown on Figure 22 (3, 5 respectively). Rubber tubing connects these taps to the two pressure switches (7, 8). The tubing from the crew compartment pressure tap passes through the tubing manifold (4) before reaching the switches. The pressure tap presently located at the Filter Unit outlet will probably be located in the crew compartment in the MBT installation.

The pressure switches actuate at the desired pressure levels. The pressure variation within the crew compartment is between 1.0 and 1.5 in. water. A pressure



1. Particulate Filter Fail-Safe Channel Tap
2. Gas Filter Fail-Safe Channel Tap
3. Crew Compartment Pressure Tap
4. Pressure Tube Manifold
5. Atmospheric Pressure Tap
6. Fail-Safe Tubing Exhaust Tap
7. Upper Limit Pressure Switch
8. Lower Limit Pressure Switch
9. Upstream Pressure Tap, Filter Pressure Drop
10. Filter Restriction Switch

Figure 22. Pressure Sensing Network.

less than 1 in. water is considered too low, and a pressure over 1.5 in. water is considered too high.

The pressure switches control the power to the airflow control valve drive motor. At a pressure less than 1.0 in. water, current to the airflow control valve drive motor causes the airflow control valve to open. A pressure over 1.5 in. water causes a reverse current that closes the airflow control valve. Between 1.0 and 1.5 in.water, no power reaches the motor. Thus, the pressure regulating system varies the airflow to the crew compartment, and maintains a predetermined pressure level.

A range of crew compartment pressure is used, rather than a single pressure, to prevent small pressure fluctuations affecting the regulating system. This reduces the operation of the airflow control valve by not correcting for those small pressure variations. Otherwise, the time lag in the system would cause the airflow control valve to continually hunt and seek.

Low crew compartment pressure status is displayed on the control panel by an indicator light and horn which connect directly to the pressure sensing circuit and give visual and audible indication of low pressure conditions. Low pressure (under 1.0 in. water) is signalled by a red flashing indicator. A warning horn actuates whenever there is a combination of low pressure and a fully open airflow control valve. This warning horn is also located in the control panel. A solenoid-held pushbutton switch can be energized to deactivate the horn during long periods of low pressure. This may occur when the Filter Unit is operating, but a crew compartment hatch is purposely left open. If the horn has been manually shut off and the compartment pressure again reaches a safe level, the solenoid automatically resets itself and warns the crew if the pressure again drops to an unsafe level.

Depressing the FIRING MODE/NOT MAX FLOW switch on the panel enables the operator to override the pressure regulating circuit. This opens the airflow control valve to give maximum airflow. This switch is used when a crew compartment pressure loss is anticipated, such as when operating a gun breech for firing. The entire switch display turns amber when first depressed. When the flow control has opened to its maximum airflow position, the upper half of the switch display lights green and the lower display is not lighted. The Filter Unit is returned to normal automatic operation by redepressing the FIRING MODE/NOT MAX FLOW switch.

c. Pressure Drop

Maximum obtainable flow through the Filter Unit depends upon the pres-

sure drop of the various components. The particulate filter is the only component whose pressure drop or air resistance rises significantly during operation in dusty conditions. Certain atmospheric conditions such as high humidity might cause the gas filter to have a higher pressure drop; however, this filter should have an essentially constant pressure drop in normal use, due to air drying of the charcoal on dry days.

With the filter in the unused, clean condition, the airflow control valve remains partially closed so that the airflow does not over-pressure the crew compartment. As the Filter Unit operates, the particulate filter pressure drop increases because of dust collection. Pressure differential across the particulate and gas filter is measured by pressure taps at the Filter Unit outlet (3) and near the pressure switch (9). The low pressure tap (3) is the same tap used for the crew compartment pressure pickup. The pressure taps connect with rubber tubing to the pressure switch (10). When the pressure differential reaches a preset value, the CHANGE FILTER indicator lamp on the control panel lights. The setting of this pressure switch depends upon the pressure rise that can be incurred before the fan is unable to maintain the desired crew compartment pressure.

The following section contains the test data which supports the design of the E49 Filter Unit and components.

VI TEST PROGRAM

Development and engineering tests were conducted to prove the design and performance of the E49 Filter Unit and components in accordance with contract and use requirements.

A DEVELOPMENT TESTS

The following paragraphs summarize the results of development tests performed on the Filter Unit and components, fabricated from Class I drawings, and PD's, in accordance with the Development Test Plan included as Appendix B of this report.

1 Shock

a. E49 Filter Unit

Shock tests, at 15 g's and 30 g's with 11 milliseconds dwell, were conducted to determine the resistance of the E49 Filter Unit to the high momentary acceleration encountered during transportation or while operating in a vehicle. The tests were in accordance with Appendix B1 of the Contract which specifies Method 516 of MIL-STD-810[30], Procedures 1 and 2. The nonoperating shock test, Procedure 2, was conducted first and the operating test, Procedure 1, was conducted upon completion of nonoperating tests.

Under shock, the gas filter exerts a good deal of pressure on the pivot pin of the vertical shock retainer which buckled under initial testing. This was corrected by changing the pin dimensions from 3/8-inch diameter to 1/2-inch diameter. This design successfully passed the shock requirements when retested.

During the operating mode of the shock tests, there were no apparent failures in either mechanical or electrical systems. At the completion of the shock tests the unit was disassembled and examined. There were no shortcomings other than that mentioned. (Reference Appendix H for test report abstract and Engineering Report No. 2437[37] for test details).

b. E67 Control Panel

The same series of shock tests were also performed on the E67 control panel.

An examination of the control panel after the operating mode of the shock test, revealed no damage or failures. The control panel operated normally during the checkout.

During the nonoperating shock tests two of the control pane switch assemblies unsnapped. The ALARM OFF switch assembly was found unsnapped after the shock pulses to the right side of the panel. Following the shock pulse to the top of the panel, both

the ALARM OFF and UNIT ON switch assemblies were unsnapped.

The unsnapping of the switches caused no permanent damage. The clip tension can be adjusted during assembly to make the mountings more secure, thus eliminating the shortcoming. The switches were snapped back into place and normal operation of the control panel was observed. (Reference Appendix H for test report abstract and Engineering Report No. 2639[38] for test details).

2 Vibration

a. E49 Filter Unit

The Filter Unit was vibrated in accordance with Appendix B1 of the Contract, with the exception that the vertical nonoperating vibration was reduced from 5 to 2.5 g's. This deviation was necessary since the available vibration equipment cannot sustain 15 to 25 cps at 5 g's. Furthermore, the 5 g's vertical and 2.5 g's in remaining planes appears to be unrealistic when compared with recent findings by the Automotive Engineering Laboratories at Aberdeen Proving Ground[33]. This deviation to Appendix B1 was made and concurred to by the Contract Project Officer on the basis of test equipment available and the referenced report.

Two deficiencies in the wiring harness occurred during the operating portion of the vibration test. Both comprised wire breakage.

The first deficiency was caused by a break in the wire cable leading to the flow control motor which caused the flow control to operate improperly.

The lugs on the No. 4 wire also pulled off during vibration because an improper crimping tool was used to secure the lugs.

These deficiencies were corrected by increasing the length of the flow control cable, thus making it more flexible and reducing wire stress. The lugs were corrected by having the manufacturer use the proper tool for crimping the lugs on the wire. The quantity of units produced did not justify purchasing this tool. Examination of the Filter Unit after vibration did not disclose any problem with other components.

From a contractual standpoint, it was only necessary to determine if the selected components would withstand the specified vibration. However, at no additional cost and a little extra effort, data was obtained which; 1) provided additional knowledge on the vibrational characteristics of the E62 precleaner section, and 2) provided information to more accurately specify the requirements of the components that mount on the E62 precleaner assembly.

The precleaner was considered a very critical component since it is comprised primarily of purchased components for which realistic specifications must be written.

The following conclusions were reached as a result of this study:

(1) The input vibration during development was amplified by the precleaner module, with the greatest amplification in the longitudinal plane.

(2) Critical frequencies may exist, and it appears that if there are critical frequencies, they are at 60, 120, 180, and 240 cps.

(3) The vibration specifications set forth in Appendix B1 of the contract are not adequate for components mounted on the precleaner such as the pressure switches, fan motor, and related control items. These components must withstand 15 g's of acceleration at 15 to 300 cps when tested as individual components and not as part of the precleaner module. Therefore, individual electronic components should be vibrated separately at 15 g's for qualification. The 15 g's acceleration insures that it can withstand the amplified accelerations encountered when mounted in the Filter Unit. (Reference Appendix H for test report abstract and Engineering Report No. 2437[37] for test details).

b. E67 Control Panel

The E67 control panel was vibrated in accordance with Appendix B1, using MIL-STD-810[30], Method 514, Table 514-1, under Equipment Class 5, Curve B, with the following exception:

The control panel was vibrated for four hours in each of three mutually perpendicular planes. The four hours were divided into one hour at -65°F and three hours at ambient intervals.

After the first four hours of vibration, a shortcoming in the HORN OFF switch occurred. It was determined that this was caused by a manufacturer's defect. The switch was replaced.

At the end of the four hours of vibration in the transverse axis, three shortcomings were noted: the ground wire to the circuit breaker indicators was broken; a crack in the plastic assembly at the rear of the Firing Mode Switch was noted; and one of

the three solder hooks on the flasher was broken.

The loop in the ground wire to the circuit breaker indicators was enlarged to relieve some of the strain at the terminal during vibration.

The manufacturer of the FIRING MODE switch was contacted about the problem and it was decided that the plastic assembly that cracked will be heavier on subsequent models.

The shortcoming of the solder hook on the flasher was caused by the weight of an unsupported capacitor and resistor soldered to it. These components were incorporated as a part of the flasher and are no longer external to the flasher housing.

During the last four hours of vibration in the longitudinal axis, no failures or damage to the panel was observed.

A complete inspection of the control panel at the completion of the vibration tests was made. There was no damage other than that mentioned. (Reference Appendix H for test report abstract and Engineering Report No. 2639[38] for test details).

3 Sand and Dust Test

The E67 control panel was subjected to the Sand and Dust Test of the Development Test Plan in accordance with MIL-STD-810[30], Method 510, Procedure 1, to determine its resistance to blowing fine sand and dust particles.

The control panel was placed in a test chamber in which a dust concentration of 0.1 to 0.25 grams per cubic foot was maintained at relative humidity of less than 30 percent. The air velocity was maintained between 100 and 500 feet per minute.

The test chamber was operated for two hours at 77°F. The temperature was then raised to 160°F and maintained for an additional two hours. The control panel was removed from the chamber, allowed to cool to room temperature, and brushed free of accumulated dust.

Visual examination of control panel components and an operational checkout revealed no evidence of damage resulting from the test. These tests were not conducted on the Filter Unit. (Reference Appendix H for test report abstract and Engineering Report No. 2639[38] for test details).

4 Humidity

a. E49 Filter Unit

The Filter Unit was tested under conditions of high temperature and humidity in accordance with Appendix B1 of the contract.

The unit was subjected to 100 percent humidity at 125°F, while operating for a period of two hours. Voltage and current were recorded during this period. The unit drew 90.0 amperes at 27.5 vdc when cold. This current draw gradually decreased as the fan motor warmed up.

Voltage was held at 27.5 vdc and chamber temperature was regulated at 125°F. Humidity was maintained at 100 percent. After reaching operating temperature, the current draw was consistently within 82 to 84 amperes throughout the duration of the test. Normal operation of the unit was observed and no failures occurred.

The unit was very hot at the end of the test - approximately 140°-150°F, but no ill effects were noted. The humidity chamber was filled with strong smelling ammonia fumes when opened at the end of test. The origin of the fumes was apparently from the gas filter.

Post-test checkout revealed nothing abnormal, electrically or mechanically , in the unit. The Filter Unit drew 56.0 amperes at minimum flow after tests as opposed to 60.0 amperes at the start and 82 amperes at maximum flow as opposed to 90.0 amperes at start. (Reference Appendix H for test report abstract and Engineering Report No. 2437[37] for test details).

b. E67 Control Panel

The E67 control panel was tested under the same conditions in accordance with Appendix B1.

The panel operated normally for the duration of the test. No increase in current was noted. Examination of the panel after the test showed no adverse effects. (Reference Appendix H for test report abstract and Engineering Report No. 2639[38] for test details).

5 Barometric Pressure

Barometric pressure tests were conducted on the E49 Filter Unit according to the procedures outlined in MIL-STD-810[30] and as specified in Appendix B1 of the Contract.

The Filter Unit was placed in a chamber and the pressure reduced to 3.4 inches of Mercury, or the equivalent of 50,000 feet above sea level. The filter chamber pressure was then increased to 23.58 inches of Mercury, or the equivalent of 10,000 feet above sea level. The Filter Unit was operated at this reduced pressure for two hours. Current draw during this period was measured every ten minutes and decreased from 78.0 amperes at start of test to 73 amperes at the end. The chamber pressure was increased to room ambient and the Filter Unit inspected. The inspection showed no evidence of damage resulting from this test. The inspection was both visual and a performance check. The Filter Unit drew 56.0 amperes at minimum flow after test as opposed to 60.0 amperes at the start and 82 amperes at maximum flow as opposed to 90.0 amperes at start. (Reference Appendix H for test report abstract and Engineering Report No. 2437[37] for test details).

The E69 control panel was not subjected to barometric pressure tests since those components which could be affected by the test, hourmeter and flasher, are both hermetically sealed and certified by the manufacturer.

6 Radio Frequency Interference

Radio noise tests were conducted at USAELRDL Field Station No. 1 in Milwaukee, Wisconsin on both the E49 Filter Unit and E67 control panel. The tests were performed in accordance with the procedures and limits set forth in MIL-S-10379A[25].

Those items in the Filter Unit which could interfere with any communications are the flasher and hourmeter in the control panel, and the fording valve motor, flow control motor, and fan motor in the Filter Unit.

No attempt was made to suppress the flasher or the hourmeter in the working model control panel and the feed-through capacitors used in the flow control proved deficient. The fording valve motor is not suppressed since it is used only for starting and stopping of the Filter Unit. Its operating duration of approximately two seconds dictates that there is no need for suppression of this component.

During the initial tests of the Filter Unit, nine individual test runs were made to determine what components would not meet the requirements of MIL-S-10379A[25]. The tests run at that time were:

a. E49 Filter Unit with working model control panel without the flow control operating.

b. The flasher and control panel operating with all other components not operating.

c. The E49 Filter Unit with the flow control operating.

d. The hourmeter operating with all other electrical components not operating.

e. Fan motor only operating, external to the unit, without radio noise interference suppression.

f. The fan motor only with a 2.5-microfarad feed-through capacitor as a radio noise suppressor.

g. Flow control motor operating, external to the unit, with no radio noise interference suppressors.

h. The flow control motor operating in the unit with all other electrical components not operating.

i. Flow control motor mounted external to the unit with an 0.1-microfarad feed-through capacitor for radio noise suppression.

Table 3 contains the test results with each of the above nine conditions listed under the test conditions column.

The maximum allowable noise level specified in MIL-S-10379A[25] for conducted tests is 80 db in the 1.5 to 10 megacycle frequency range and 74 db in the 10 to 40 megacycle band.

These tests were conducted only. From test results it was obvious that the hourmeter and flasher must be suppressed to meet the requirements of the specification and that the capacitors used for the flow control motor were defective as radio noise filters. The Filter Unit was reworked with the following changes to the unit:

1. Feed-through capacitors for the flow control motor were purchased from another vendor.

2. An 0.1-microfarad 100-volt capacitor was connected across the negative and positive terminals of the hourmeter.

3. A solid state flasher was purchased which was integrally shielded and radio noise suppressed.

TABLE 3. RADIO NOISE TESTS

Freq, megacycles	Ambient Noise	TEST CONDITIONS								
		a	b	c*	d	e	f	g	h	i
1.7	66	72	96	72	83	98	74	91	99	61
3	56	66	83	66	87	96	75	98	104	57
5	44	67	60	78	88	85	77	104	98	59
8	40	65	53	65	92	87	76	105	92	52
12	43	64	A**	74	90	81	73	110	96	47
16	40	A	A	78	92	80	68	108	98	43
20	40	66	A	76	72	80	61	109	89	50
24	38	51	A	82	97	66	59	104	84	49
28	38	67	A	75	90	76	61	99	88	49
30	38	64	A	73	92	73	58	90	82	50

* Complete unit operating as it will in a vehicle

** Ambient Noise

With these modifications, and with an E67 control panel, the unit was retested. The unit was tested for both radiated and conducted interference and the Filter Unit did not exceed the RFI limits specified by MIL-S-10379[25].

Additional tests were run on the Filter Unit with the shielding of the power leads of the fan assembly removed. There was no change in the performance of the Filter Unit from a radio noise standpoint with, or without, the shielding.

The results of conducted radio noise tests of the fan assembly are shown in Table 3, test e before suppression and test f after suppression. This is the noise that has been generated by the fan only, and is of primary value when analyzing the entire Filter Unit from a radio noise standpoint. The radio noise specification for this component is the conducted radio noise tests of MIL-S-10379[25].

Appendix C contains the certification of tests by USAELRDL.

7 Dust Capacity

The purpose of this test was to establish that the E49 Filter Unit could deliver 400 cfm of purified air at 1-inch of water after being subjected to an environment of 0.025 gm/cu ft of AC Coarse Test Dust for a period of 24 hours.

The Filter Unit was operated continuously at 400 cfm for 24 hours. At no time was the unit shut down during the test. AC Coarse Test Dust was fed at the rate of 0.025 gm/cu ft of air with a modified AFI dust feeder. The modification of the dust feeder consisted of replacing the 1-rpm motor with a 6-rpm motor and adjusting the height of the dust in the feeding tray to provide the desired dust concentration. The voltage to the Filter Unit was held at a constant 27.5 ± 0.5 volts dc.

During the 24 hours of operation, a total of 15,840 grams of dust were fed. This is based on the entering airflow of 440 cfm.

After 19 hours of operation, or 12,540 grams of dust, the indicating light denoting a loaded filter lit. This light is activated by a pressure switch with an arbitrary setting. Whether 19 hours of operation, or 12,540 grams of dust, is the proper point to have this light activate will have to be determined.

To gain additional knowledge on the characteristics of the E49 Filter Unit, the FIRING MODE switch was depressed, which opened the flow control to its maximum position. Under these conditions the flow to the test chamber was limited to 400 cfm and the pressure in the chamber was measured at 1.4-inch of water. With the unit in this same mode of operation, the flow was increased by using an auxiliary blower until the pressure in the test chamber reached 1-inch of water. The flow under these conditions measured 405 cfm.

At the completion of the 24-hour dust capacity test, the mechanical flow control, which regulates the output of the E49 Filter Unit, had not reached its maximum position. It may be concluded that the dust life of the Filter Unit is in excess of the 24-hour contract specified requirement.

8 Rain and Dust Test

A combination rain and dust test of the Filter Unit was conducted to determine if airflow control valve operations would be affected by mud buildup and if unit performance would be impaired.

The test consisted of alternating six hours of dust at zero visibility with six hours of rain at 4.0 inches/hour for 24 hours. The unit was operated at 400 cfm for the duration of testing.

Water accumulation in the precleaner section was measured periodically and never exceeded more than 1/16-inch deep. During the rain test it was noted that water striking the deep-fording valve cover was flowing around the in-turned edge and into the air inlet. A ridge was added to the periphery of the cover with a notched groove over the dust exhaust deflector and this test was reobserved after this modification. The majority of water was thus removed without entering the precleaner. This design was therefore incorporated into later Filter Unit designs.

The Filter Unit operated satisfactorily during the entire test. The lower portion of the particulate filter was damp, but this occurred before adding the lip to the deep-fording valve cover. The particulate filter met the efficiency requirements of this contract after test and all electrical components functioned properly. There was no observable mud buildup around the airflow control valve and it appeared that the dust separator was effective in removing the majority of rain entering the air inlet.

9 Snow Tests

Snow tests of the E49 Filter Unit only were conducted under actual environmental conditions in an unsheltered location. These tests were not a contract requirement, but were performed with Government approval to determine if the unit would perform satisfactorily under inclement Arctic conditions.

The Filter Unit was connected to the plenum chamber for standard 400 cfm operation and the unit was operated during the duration of test. Two tests were conducted; the first test for a period of 3 hours at a temperature of 19°F and with a total snow fall of 2.5 inches, and the second test for a period of 3 hours at a temperature of 16°F with a total snow fall of 1.25 inches.

The particulate filter accumulated 30 grams of frost in the central region during the first test. There was a considerable amount of frost in upper corners of the precleaner section, around the inlet casting, on electrical components of the precleaner assembly, and within the tube section. The snow did not adversely affect unit operation and there was no accumulation of water within the housing.

There was no accumulation of frost on the particulate filter after the second test. A small amount of frost collected on the inlet casting. The unit continued to operate

satisfactorily during this test. It may be concluded from these tests that the Filter Unit will operate satisfactorily under conditions of above normal snow fall.

10 Fail-Safe Tests

Fail-safe sealing of the Filter Unit was tested at maximum, minimum, and absolute minimum flow to determine if fail-safe channels are under adequate negative pressure at all flow conditions. These channels must be under negative pressure at all times in order to draw any possible leakage at the filter gaskets back to the air inlet for repurification.

The precleaner assembly was tested out of the housing with pressure readings taken at the line to the fail-safe channels. To obtain absolute minimum flow, the edge of the airflow control valve plates were taped and pressure was applied to the outer stationary plate. The following pressure readings were made:

Airflow, cfm	Pressure in Fail-Safe Line, inches of water
Maximum Flow (approx 400 cfm)	-4.40
Minimum Flow (approx 135 cfm)	-0.68
Absolute Minimum Flow (approx 50 cfm)	-0.35

As a result of this test, it appears that fail-safe channels in the Filter Unit are under adequate negative pressure at all flow conditions to provide the required feedback of any leakage at the filter gaskets.

11 Airflow Versus Pressure Drop

The contract requires that the Filter Unit deliver 400 cfm of air at one inch of water after operation for 24 hours in an atmosphere containing 0.025 grams per cubic foot of AC Coarse Test Dust. This requirement allows additional capacity if the Filter Unit has not operated for a period of 24 hours in this environment. The additional capacity could be advantageous if a greater amount of air than 400 cfm were required. This additional capacity, of course, would be at the expense of dust life.

The Feasibility Study [10] projected that a clean E49 Filter Unit would deliver approximately 540 cfm of air against 1-inch of water. At this airflow, the Filter Unit would have virtually no dust life. That is, any additional restrictions in the Filter Unit would reduce the output of the unit to less than 540 cfm. The reverse of this is also true. If the leakage rate or the delivery requirement of the Filter Unit is reduced to less than 400 cfm, the dust capacity of the Filter Unit can be increased.

The unit was connected to a plenum chamber and the flow was measured with a flow nozzle at the chamber outlet. The pressure drop was taken across the tube section and both gas and particulate filters by utilizing pressure taps at the blower outlet and plenum chamber. Table 4 contains the recorded pressure drop at various flows.

TABLE 4. PRESSURE DROP VERSUS FLOW

Airflow, cfm	Pressure Drop, in of water	Voltage, volts dc	Projected Life, hrs at zero visibility
510	14.0	27.5	2
450	11.3	27.5	15
400	9.4	27.5	30
350	7.5	27.5	48
300	5.8	27.5	70
250	4.5	27.5	107
200	3.6	27.5	169
150	2.7	27.5	302
100	2.1	27.5	618

From these results it may be concluded that the Filter Unit pressure drop is well within the established design limits.

12 Airflow Regulation

The contract requires that the Filter Unit have controllable airflow between 135 and 400 cfm of air. This test was run with the pressure sensing network in operation and the flow control plates fully closed. The Filter Unit satisfactorily regulated the airflow down to 115 cfm of air with a crew compartment pressure of 1 inch of water.

13 Acoustical Noise

The acoustical noise of the fan assembly is of prime importance since the components within the E49 Filter Unit which will act as sound attenuators are of fixed geometric shape and should remain relatively constant regardless of the fan assembly.

The acoustical tests were conducted in an anechoic chamber. The test equipment consisted of a condenser microphone with a flat frequency response of 18 kilocycles ±3 db, a sound vibration analyzer with a flat frequency response of 30 kilocycles ± 3 db, and related calibration equipment. Readings were taken on a 5-foot radius in a horizontal plane that passes the geometric center of the fan. Readings were taken at the inlet of the fan in an arc of 0 to 90 degrees in 30 degree increments, positions 1-4, respectively in Table 5. The sound level at the output side of the fan was also determined. It was not possible to make these readings in a 0 to 90 degree arc since from 0 to 45 degrees the airflow from the fan interferred with sound pressure readings. Therefore, readings were taken at 45, 60, and 90 degrees, position 5-7, respectively in Table 5. The fan was operated under free flow conditions.

The data was recorded in nine octave bands with an Overall Sound Pressure Level (OASPL) and in Perceived Noise (PNdb). OASPL is the noise which may damage the human ear whereas PNdb is a measure of irritability.

TABLE 5. OCTAVE BAND LEVELS

Posn	OASPL	OCTAVE BANDS									
		1	2	3	4	5	6	7	8	9	PNdb
1	90.2	71.8	67.6	68.7	60.4	66.9	77.2	86.7	86.5	77.4	103.2
2	89.4	69.5	67.5	65.1	64.2	69.1	79.1	86.2	84.2	78.7	102.7
3	90.2	67.8	67.7	76.6	63.6	67.9	76.4	87.9	84.1	76.9	103.9
4	85.5	68.2	69.3	91.3	60.9	64.0	72.0	81.1	76.5	69.3	98.1
5	95.0	67.2	70.0	80.8	72.4	77.2	88.4	91.4	88.5	82.2	108.5
6	94.7	67.9	70.3	84.5	70.9	77.1	87.5	91.0	87.8	81.6	108.2
7	92.9	69.1	73.9	89.4	65.8	73.3	84.5	87.5	81.5	74.8	105.1

From this data, it is concluded that both the OASPL and PNdb noise levels are within the acceptable range.

14 Fan Performance

The fan assembly met the requirements of producing a minimum of 440 cfm at 20 inches of water with a maximum current draw of less than 90 amps at 27.5 vdc as plotted in Figure 23.

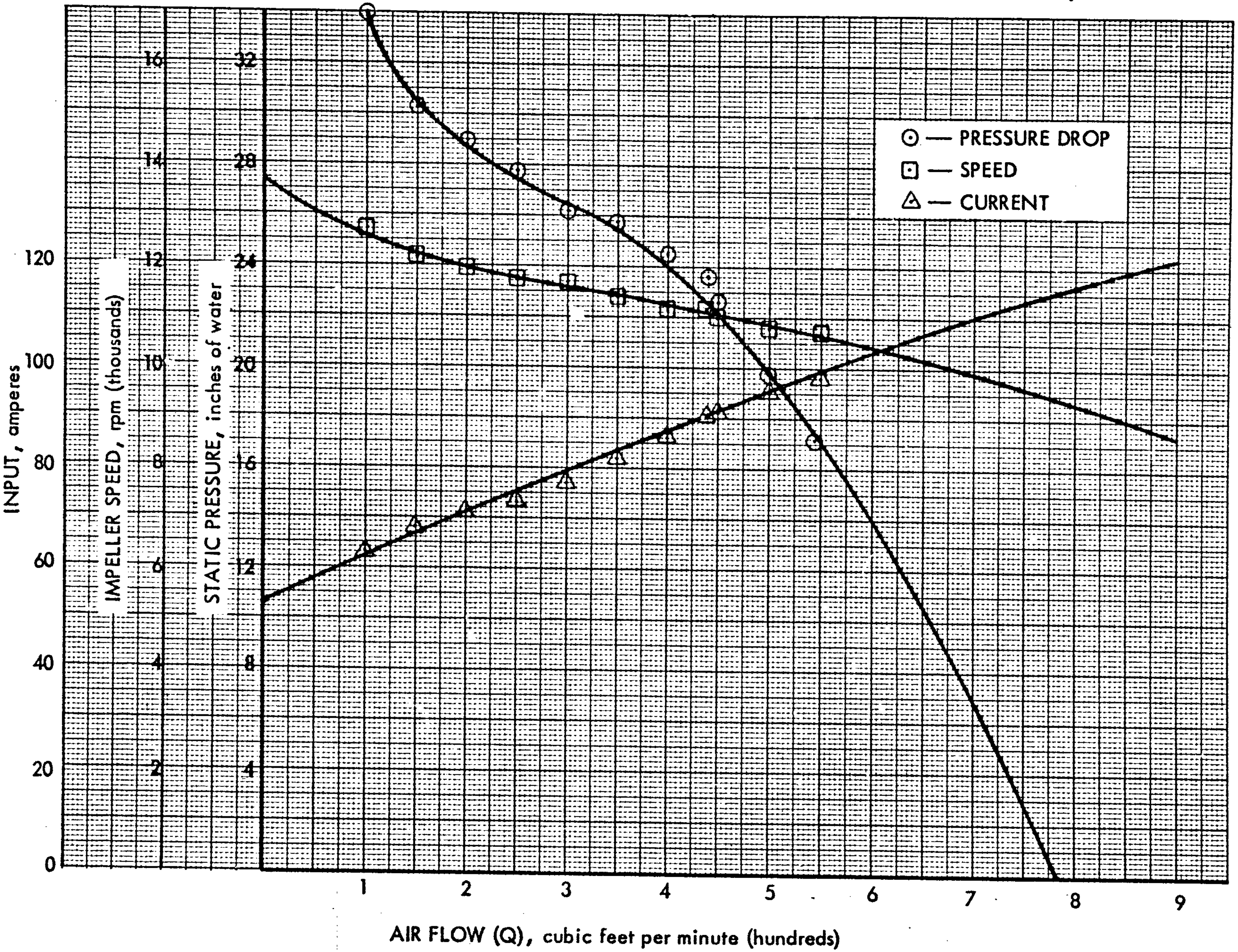


Figure 23. Fan Performance.

The test apparatus used in checking fan performance consisted of an orifice and an airflow control valve coupled to the fan assembly by means of an adapter. Manometers were used to measure the static pressure at the fan outlet and the pressure drop across the orifice. A voltmeter and ammeter were used to monitor voltage and current to the fan motor. An electronic pulse counter connected across the power leads measured impeller speed.

The airflow was varied using the airflow control valve and the static pressure, impeller speed, and input current were recorded for specific airflows.

The fan meets the requirements of air supply and current draw without a saddle condition at various delivery rates.

15 Fan Endurance

The Development Test Plan specifies a fan endurance test. However, this is more of a reliability test, and as such, was conducted as a part of the reliability demonstration, Paragraph VIII A.

16 Fan Impeller Erosion

This test was performed to determine if the fan assembly could ingest a large amount of dust without affecting its performance.

The fan was operated at approximately 440 cfm at 20 inches of water on 27.5 volts dc. A mechanical, high-volume dust feeder was used to feed 140- mesh silica flour. This dust was selected instead of AC Coarse Test Dust because of its abrasive quality and it is the dust specified in MIL-STD-810[30] for sand and dust test. Dust was fed to the fan for 57 hours, during which time 88,133 grams of dust were fed. At the end of the 57 hours the fan could no longer operate. However, this was not considered a failure since this is more dust than a fan would ever see in 500 hours of operation which is the normal time for brush and bearing maintenance. It is over 14 times longer than the standard dust tests of MIL-STD-810. Ideally. this test should be performed with the fan motor not in the system, but such a test setup would be very difficult, if not impossible, to run.

Prior to starting the test, a performance test was run on the fan assembly for comparison purposes at the completion of the test. At the end of 57 hours, the motor was replaced and the performance test of this assembly was run.

Although the impeller showed considerable wear at the end of test, losing approximately 375 grams, the performance of the fan was still acceptable and the power requirement had actually decreased. Although the test was not run the intended 80 hours, it

was felt that sufficient information had been gained to project that, at the end of 80 hours, fan performance would not decrease more than 10 percent.

17 Dust Separator Pressure Drop

An airflow versus pressure drop test was performed on the mechanical dust separator section only. This test was conducted on a flow bench with a constant scavenging airflow of 40 cfm to simulate the actual flow characteristics of this component when used in a precleaner. Ideally, this test would be conducted on the E62 precleaner, but the complexity of the test setup would eliminate any advantages gained by testing this component in its normal environment.

Figure 24 shows the pressure drop lost across this system at various airflows. The pressure drop is within the design limits.

18 Particulate Filter Performance

The performance of the particulate filter is equated with pressure drop through the filter and its efficiency or penetration on DOP smoke. The average airflow resistance of all particulate filters fabricated under this contract, paragraph VB, are the best evidence of overall performance. The results of penetration tests on particulate filters from development testing are contained in Table 6.

TABLE 6. E59 PARTICULATE FILTER EFFICIENCY AFTER PERFORMANCE TESTS

Air Flow, cfm	Efficiency, percent				
	Initial	Barometric Pressure	Humidity	Shock	Vibration
200	99.993	100.00	99.995	99.994	99.984
400	99.997	99.997	99.997	99.992	99.983

Particulate filter efficiency, at both 200 and 400 cfm, exceeds the acceptable level of 99.97 percent.

19 Gas Filter Pressure Drop

Gas filter resistance to airflow is of prime importance since this is a major contributor to the overall pressure drop of the E49 Filter Unit. The data gathered from tests on eight filters is shown in Table 7 and plotted in Figure 25.

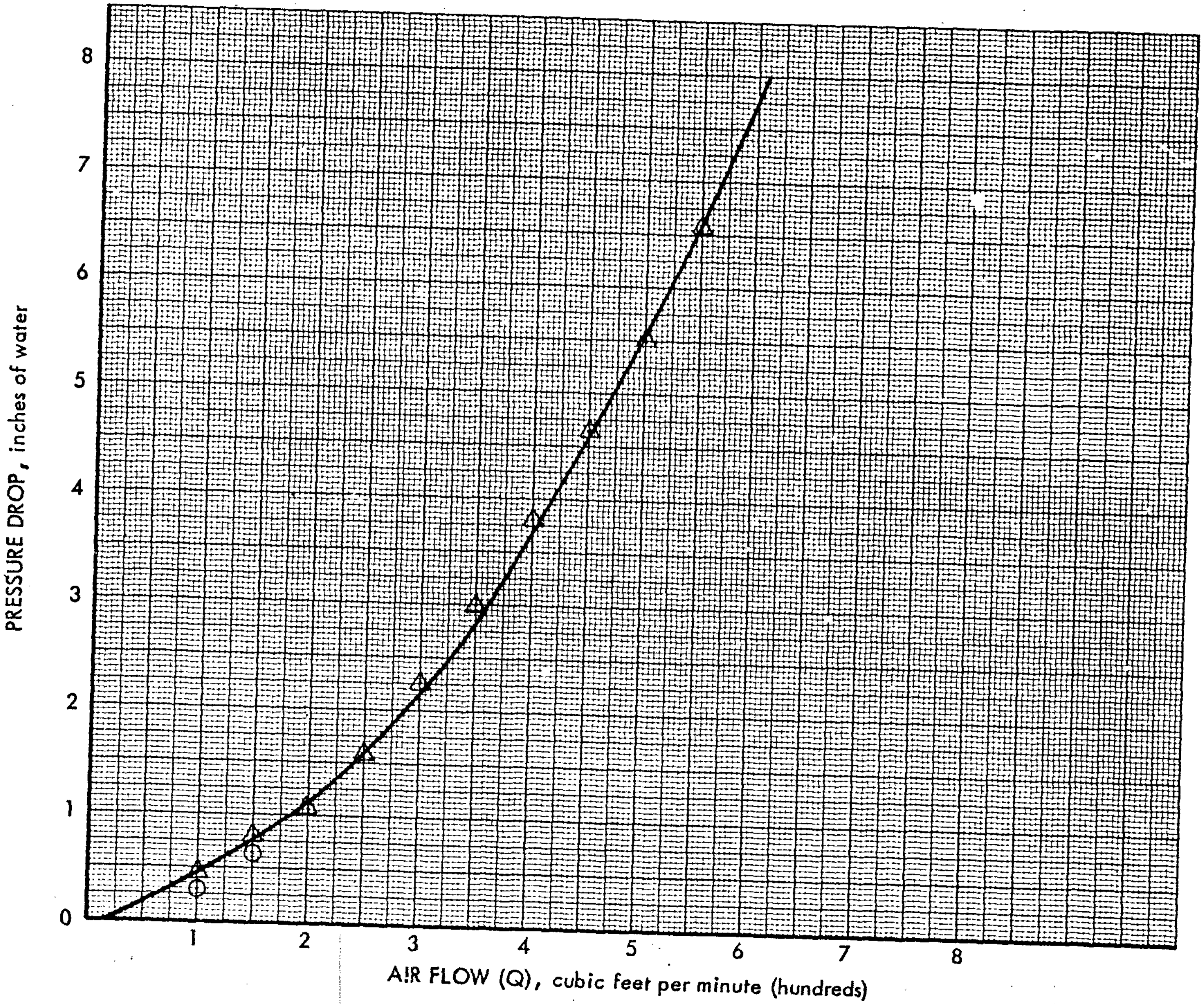


Figure 24. Pressure Drop of Precleaner Tube Section.

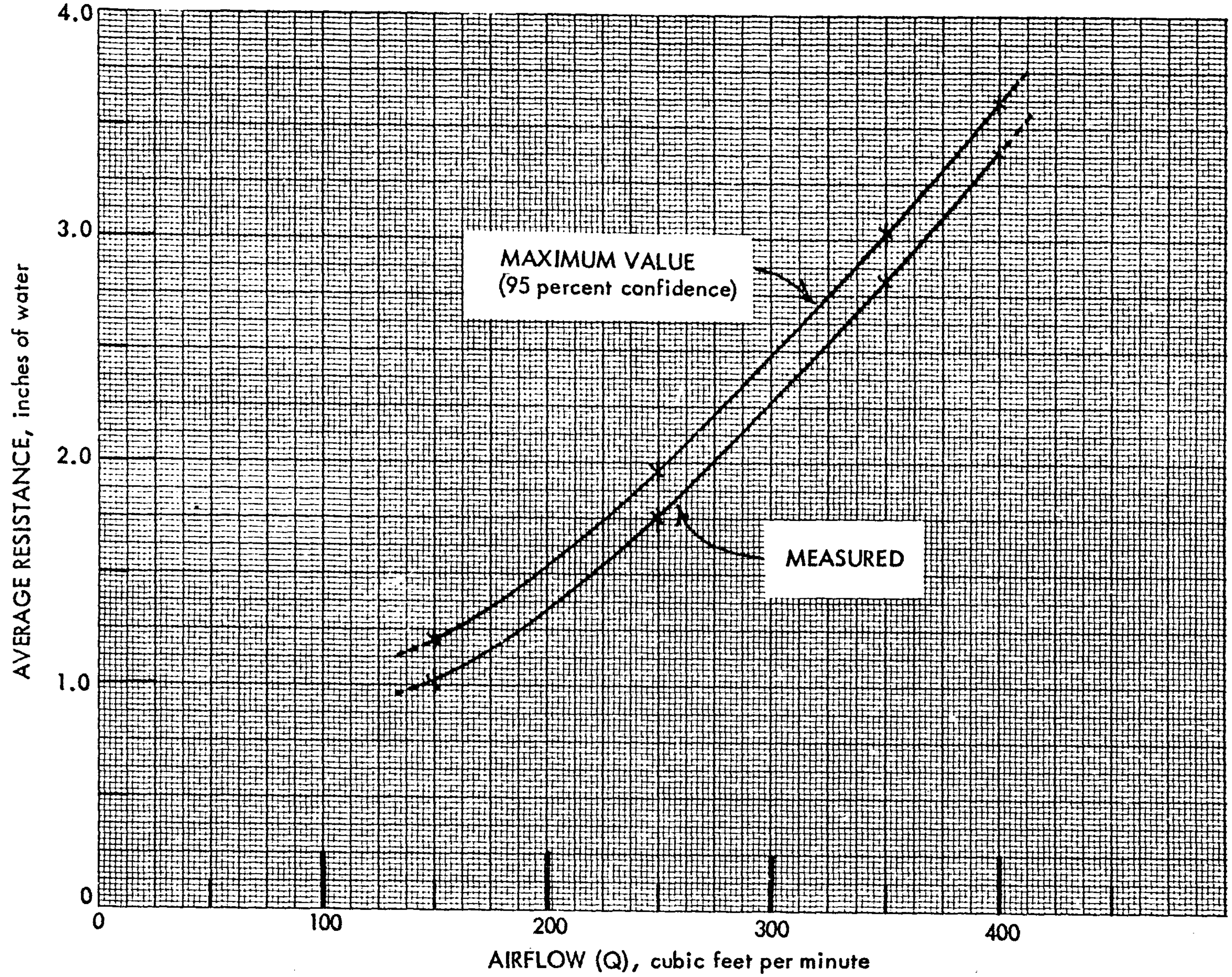


Figure 25. E61 Gas Filter Resistance.

TABLE 7. E61 GAS FILTER AIRFLOW RESISTANCE AT VARIOUS FLOWS

Airflow, cfm	Average Resistance, in. of water	Maximum Value With 95% Confidence, in. of water
150	1.05	1.23
250	1.74	1.96
350	2.84	3.12
400	3.35	3.63

The gas filter resistance is within design limits at all flows.

20 Sand and Dust Test on Control Panel

A sand and dust test was performed in accordance with MIL-STD-810[30], Method 510, Procedure 1, to determine the resistance of the control panel to blowing fine sand and dust particles.

A visual and operational examination of the control panel following the test revealed no evidence of damage resulting from the test and there was no penetration beyond panel seals.

B ENGINEERING TESTS

The data presented in this section summarizes the engineering tests conducted to check the performance of the E49 Filter Unit and components.

Test procedures with the exception of gas filter Freon adsorption are described in Appendix B.

The Freon adsorption test apparatus consists of a blower, flow control, flow measuring device, heater section, Freon-introduction system, upstream mixing section, upstream sampling system, gas filter clamping device, downstream mixing section, downstream sampling system and concentration analyzing system. It is supported by a metal framework, doubled back on itself to allow recirculation or exhaust, as desired.

The Freon introduction section consists of a Freon-12 source, a regulator and valve system to control the flow. A series of baffles, both upstream and downstream of the gas filter, provides maximum mixing in the shortest distance. Each series of baffles is followed by a series of sampling nozzles to insure that the gas stream samples are representative

of the upstream and downstream concentration. The sampling system is connected through a solenoid-operated switching system to the detection system. The detection system consists of both a halogen leak detector for measuring low gas concentrations and a nondispersive infrared spectrophotometer for measuring the higher concentrations. A switching system permits either of these two instruments to be used with the sampling system. The switching system allows sampling either upstream of downstream gas concentrations or calibrating the spectrophotometer using purified air with a 50 ppm nitrogen/Freon-12 mixture or a 1000 ppm nitrogen/ Freon-12 mixture.

Table 8 contains the Freon and DOP test results for two Modified E49 Filter Units assembled under this contract for a related application.

TABLE 8. MODIFIED E49 FILTER UNIT TEST RESULTS

Date	Filter Unit Serial No.	DOP Penetration, Percent	Freon-12 Penetration, ppm
20 Jan 65	1029619A11	.002 at 200 cfm	Less than 1.0 *
		.005 at 400 cfm	Less than 1.0 *
21 Jan 65	1049619A11	.001 at 200 cfm	Less than 1.0 *
		.003 at 400 cfm	Less than 1.0 *

* See following paragraph

No leaks were detected using Freon gas. Experimentation to determine the sensitivity of gas leak detection proved that a 1.5 ppm leak could be detected through a 1/8-inch diameter hole in the precleaner cover. The sensitivity of the instrumentation used further assures confidence in detecting leaks down to 1 ppm. Any leakage less than this amount cannot be measured with the Government-approved instrumentation used. However, both DOP and Freon penetration are well within the established limits.

Table 9 contains characteristic data on the E59 particulate filter obtained from DOP testing of two separate filters. This data is plotted in Figure 26. The DOP dispersal generator (pneumatic) used by Donaldson Company, disperses a heterogeneous mixture of DOP with a mean diameter of 0.3 microns whereas DOP testing by CRDL is with a homogeneous mixture of 0.3 micron mean diameter DOP (thermally dispersed). However, test result correlation between the two facilities is quite precise.

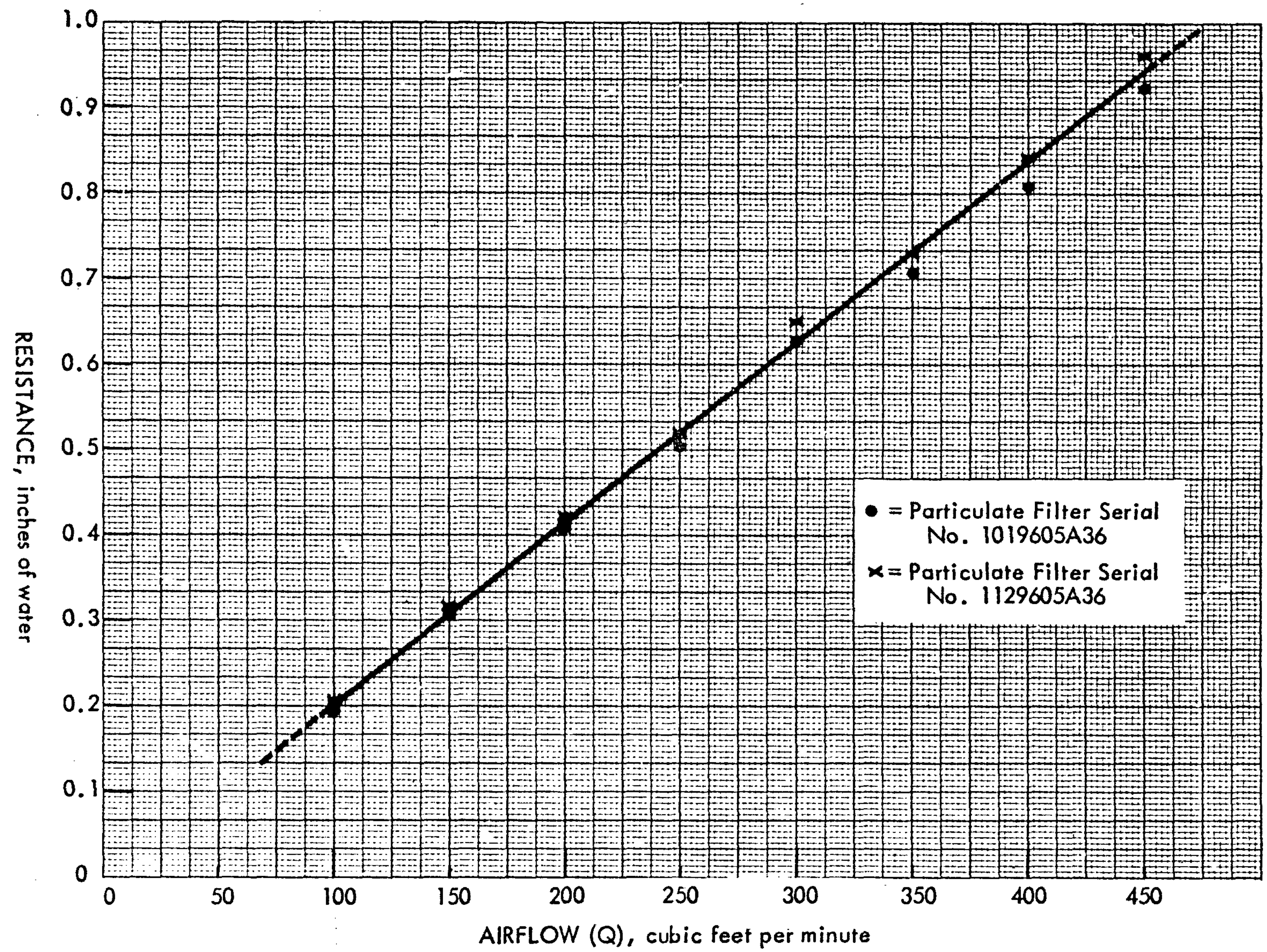


Figure 26. E59 Particulate Filter Characteristics Data.

TABLE 9. E59 PARTICULATE FILTER CHARACTERISTICS DATA

Airflow, cfm	Resistance, inches of water	
	Filter No. 1019605A36	Filter No. 1129605A36
100	0.195	0.21
150	0.305	0.32
200	0.41	0.43
250	0.51	0.53
300	0.625	0.65
350	0.705	0.73
400	0.82	0.845
450	0.93	0.96

Table 10 contains the results of Donaldson Company and CRDL DOP and pressure drop tests of particulate filters fabricated and shipped under this contract. The results of these tests prove the design of the particulate filter within the contract-specified limitations on penetration.

TABLE 10 PARTICULATE FILTER TESTS

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.	After Environ Storage			After Shock & Vibration		
						Type	% DOP	Res	Type	% DOP	Res
1009605A36	400			0.004	0.97						
	200			0.004	0.53						
1019605A36	400	0.005	0.80	0.003	0.80	Arctic	.003	.86	Shock	.005	.89
	200	0.002	----	0.001	0.83		.001	.43	& Vib	.004	.47
1039605A36	400	0.007	0.79	0.004	0.79	Arctic	.004	.85			
	200	0.009	----	0.004	0.41		.004	.43			
1049605A36	400	0.013	0.79	0.003	0.79	Desert	.004	.86			
	200	0.010	----	0.003	0.41		.003	.43			
1059605A36	400	0.007	0.80	0.003	0.80	Desert	.005	.85	Vib	.003	.99
	200	0.007	----	0.005	0.41		.006	.45		.005	.43
1069605A36	400	0.002	0.78	0.002	0.78	Tropic	.003	.84	Vib	.006	.96
	200	0.002	----	0.004	0.41		.006	.41		.004	.42
1079605A36	400	0.004	0.80	0.004	0.80	Tropic	.004	.91			
	200	0.003	----	0.001	0.43		.001	.45			
1099605A36	400	0.008	0.81	0.002	0.81	Cyclic	.004	.86			
	200	0.006	----	0.003	0.41		.003	.45			
1109605A36	400	0.006	0.74	0.003	0.74	Cyclic	.003	.85			
	200	0.002	----	0.007	0.40		.006	.42			

TABLE 10. PARTICULATE FILTER TESTS (continued)

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.	After Blast Shock of Unit		
						PSI	% DOP	Res
1119605A36	400	0.005	0.78	0.002	0.78	2	0.03	0.87
	200	0.002	----	0.003	0.41		0.03	0.43
1129605A36	400	0.005	0.82	0.005	0.82	2	0.02	0.94
	200	0.004	----	0.006	0.43		0.03	0.50
1139605A36	400	0.004	0.79	0.003	0.79	15	0.02	
	200	0.004	----	0.005	0.41			
1149605A36	400	0.005	0.78	0.003	0.78			
	200	0.004	----	0.004	0.41			
1159605A36	400	0.004	0.76	0.006	0.76			
	200	0.003	----	0.003	0.41			
1169605A36	400	0.008	0.81	0.008	0.81			
	200	0.009	----	0.008	0.43			
1179605A36	400	0.015	0.81	0.004	0.81			
	200	0.013	----	0.002	0.43			
1189605A36	400	0.003	0.78	0.003	0.78			
	200	0.003	----	0.003	0.41			
1199605A36	400	0.004	0.77	0.006	0.77			
	200	0.004	----	0.003	0.41			
1209605A36	400	0.005	0.79	0.004	0.79			
	200	0.004	----	0.005	0.42			

TABLE 10. PARTICULATE FILTER TESTS (continued)

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.	After Blast Shock of Unit		
						PSI	% DOP	Res
1219605A36	400	0.005	0.78	0.007	0.78			
	200	0.004	----	0.004	0.42			
1229605A36	400	0.004	0.80	0.005	0.80			
	200	0.006	----	0.006	0.41			

Filter Serial No.	Airflow, cfm	DCI %DOP	DCI Res.	CRDL % DOP	CRDL Res.	After Altitude		After Humidity		After Shock		After Vibration
						ΔP	DOP	ΔP	DOP	ΔP	DOP	DOP
1569605A36	400	0.005	0.95	.003	0.97							
	200	0.006	0.6	.002	0.53							
1579605A36	400	0.003	0.95	.004	0.94							
	200	0.002	0.6	.004	0.42							
1589605A36	400	0.008	0.95	.002	0.97							
	200	0.010	0.6	.002	0.43							
1599605A36	400	0.003	0.95	.005	0.89							
	200	0.003	0.6	.004	0.39							
1619605A36	400	0.004	0.95									
	200	0.002	0.7									
1639605A36	400	0.006	0.95									
	200	0.006	0.6									

TABLE 10. PARTICULATE FILTER TESTS (continued)

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.
1659605A36	400	0.024	0.9		
	200	0.024	0.6		
1669605A36	400	0.005	1.0		
	200	0.008	0.5		
1679605A36	400	0.006	1.0		
	200	0.003	0.4		
1689605A36	400	0.003	1.0		
	200	0.005	0.5		
1699605A36	400	0.005	1.0		
	200	0.007	0.4		
1709605A36	400	0.005	1.0		
	200	0.003	0.4		
1719605A36	400	0.005	1.0		
	200	0.004	0.5		
1729605A36	400	0.007	1.0		
	200	0.010	0.5		
1739605A36	400	0.001	1.0		
	200	0.002	0.4		
1749605A36	400	0.002	1.0		
	200	0.003	0.5		

TABLE 10. PARTICULATE FILTER TESTS (continued)

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.
1759605A36	400	0.003	0.9		
	200	0.006	0.4		
1769605A36	400	0.006	0.9		
	200	0.004	0.5		

Table 11 contains the results of Freon and pressure drop tests by Donaldson Company and CRDL on gas filters fabricated under this contract.

Freon testing of all filters was not performed by Donaldson Company because of a failure of the infrared analyzer in the test equipment. Because of the subsequent curing time required for the new analyzer, the Government approved submission of these filters without Freon testing.

The result of these tests prove the design of the vertical E61 gas filter in accordance with contract requirements.

In addition to the above tests, vibration, shock, and climate tests were conducted by the Field Evaluation Division (FED) at CRDL on eleven particulate and ten gas filters. The following paragraphs summarize the FED test method and results. These results are also summarized in Tables 12 and 13 for three of each of the above filters.

Vibration Tests.

Three particulate filters (Serial Nos. 1069605A36, 1019605A36 and 1059605A36) and three charcoal filters (Serial Nos. 1089606A109, 1019606A109 and 1039606A109), mounted in their filter housings (one particulate and one charcoal filter, per housing) were subjected to vibration test schedules outlined in MIL-STD-810[30], Method 514, Table 514-1, Equipment Class 5, Ground Vehicles, Curve B, with the exception that vibration was conducted for four hours in each of three directions, vertical, longitudinal and transverse, sweeping the range of 15 to 300 cps at a cycling rate of 7.5 minutes. The longitudinal and transverse positions were cycled from 25 to 300 cps. This was due to the exiter trunnions flexing while driving the horizontal test table. No external structural damage was observed to any of the filters on completion of the vibration test. Leakage of powdered charcoal, especially at the lower frequency, was observed on all three charcoal filters. The three particulate filters were then returned to Physical Protective Division for DOP penetration and resistance tests. The three gas filters were returned to Physical Protection Division for CG life and resistance tests.

Shock Tests.

One particulate filter (Serial No. 1019605A36) and one gas filter (Serial No. 1019606A109), previously subjected to vibration tests, were subjected to a shock test in accordance with MIL-STD-810[30], Method 516, Procedure I. Three shocks in each direction were applied along the three mutually perpendicular axis of each filter for a total of 18 shocks per filter at 15 g peak acceleration. No external structural damage was observed to the fil-

TABLE 11. GAS FILTER TESTS

Filter Number	Donaldson Co. Data				CRDL Data					Test Conditions
	Design	Airflow, cfm	Rest, in. of H_2O	Freon Life, sec.	Airflow, cfm	Rest, in. of H_2O	CG Life, min.	Airflow, cfm	Freon Life, sec.	
1039606A94	Vert				400	3.7				
1049606A94	Vert.	360	2.82	185	400	3.7		318	267	
1059606A94	Vert.				400	3.8				Cyclic, APG
1079606A94	Vert.				400	3.6				Tropic, APG
1089606A94	Vert.				400	3.6				Desert, APG
1099606A94	Vert.				400	3.6				Arctic
1109606A94	Vert.	345	2.91	208	400	3.7				Fort Knox
1009606A109	Horiz.				400	4.7	30.5			Control filter
1019606A109	Horiz.	335		424	400	4.6	25.8	318	532	Shock and vibration
1029606A109	Horiz.	314	3.64	297	400	5.3		308	477	
1039606A109	Horiz.	305	3.27	257	400	4.8	22.1	312	409	Shock and Vib
1059606A109	Horiz.				400	4.9				Arctic Tests
1069606A109	Horiz.				400	4.7	27.5			Tropic, R.H./1 hr
1079606A109	Horiz.				400	4.6				Desert Tests
1089606A109	Horiz.				400	4.7	23.7			Vibration/12 hrs

TABLE 11. GAS FILTER TESTS (continued)

Filter Number	Donaldson Co. Data				CRDL Data					Test Conditions
	Design	Airflow, cfm	Rest, in. of H_2O	Freon Life, sec.	Airflow, cfm	Rest, in. of H_2O	CG Life, min.	Airflow, cfm	Freon Life, sec.	
1109606A109	Horiz.				400	4.7				
1059606A134	Vert.	400	3.7		400	3.4				
1079606A134	Vert.	400	3.6		400	3.6	22.3			Pkg drop test
1129606A134	Vert.	400	3.6		400	3.9	13.2			Shock and Vib by DCI
1149606A134	Vert.	400	3.8							
1159606A134	Vert.	400	3.7							
1169606A134	Vert.	400	3.7		400	3.6				
1299606A134	Vert.	400	3.35							
1309606A134	Vert.	400	3.35							
1319606A134	Vert.	400	3.30							
1329606A134	Vert.	400	3.35							
1339606A134	Vert.	400	3.30							
1349606A134	Vert.	400	3.30							
1359606A134	Vert.	400	3.35							
1369606A134	Vert.	400	3.30							

TABLE 11. GAS FILTER TESTS (continued)

Filter Number	Design	Donaldson Co. Data			CRDL Data					Test Conditions
		Airflow, cfm	Rest, in. of H_2O	Freon Life, sec.	Airflow, cfm	Rest, in. of H_2O	CG Life, min.	Airflow, cfm	Freon Life, sec.	
1379606A134	Vert.	400	3.30							
1389606A134	Vert.	400	3.40							
1399606A134	Vert.	400	3.30							
1409606A134	Vert.	400	3.25							

TABLE 12. TEST SUMMARY OF PARTICULATE FILTERS

Filter Serial No.	Airflow, cfm	DCI % DOP	DCI Res.	CRDL % DOP	CRDL Res.	After Environ Storage			After Shock & Vibration		
						Type	% DOP	Res	Type	% DOP	Res
1019605A36	400	0.005	0.80	0.003	0.80	Arc-	.003	.86	Shock	.005	.89
	200	0.002		0.001	0.83	tic	.001	.43	& Vib	.004	.47
1059605A36	400	0.007	0.80	0.003	0.80	Desert	.005	.85	Vib	.003	.99
	200	0.007		0.005	0.41		.006	.45		.005	.43
1069605A36	400	0.002	0.78	0.002	0.78	Tropic	.003	.84	Vib	.006	.96
	200	0.002		0.004	0.41		.006	.41		.004	.42

TABLE 13. TEST SUMMARY OF GAS FILTERS

Filter Number	Donaldson Co. Data				CRDL Data					Test Conditions
	Design	Airflow, cfm	Rest, in. of H_2O	Freon Life, sec.	Airflow, cfm	Rest, in. of H_2O	CG Life, min.	Airflow, cfm	Freon Life, sec.	
1019606A109	Horiz.	335		424	400	4.6	25.8	318	532	Shock and Vibration
1039606A109	Horiz.	305	3.27	257	400	4.8	22.1	312	409	" "
1089606A109	Horiz				400	4.7	23.7			Vibration, 12 hours

ters, but powdered charcoal was observed leaking from the charcoal filter. This loose charcoal could have been powdered loose during vibration testing and came out during the shock impact. The filters were then returned to Physical Protective Division for DOP penetration and resistance tests on the particulate filter and CG life and resistance tests on the charcoal filter.

Climatic Tests.

Fifteen filters, eight particulate and seven charcoal, not subjected to shock or vibration tests, were exposed to climatic extremes for a 3-week period in accordance with the following schedule:

Condition	No. of Items	Filter Type
-65°F (Arctic)	2	Gas
-65°F	2	Particulate
160°F (Desert)	2	Gas
160°F	2	Particulate
113°F, 85 percent rel. humidity (Tropical)	2	Gas
113°F, 85 percent rel. humidity	2	Particulate
Cyclic*	1	Gas
Cyclic*	2	Particulate

(*) These filters were subjected to storage for one week at each of the following conditions; 160°F, -65°F and 113°F, 85 percent relative humidity, in this order.

On completion of the storage period the filters were returned to the Physical Protection Division for DOP penetration and resistance testing. (See Tables 10 and 11).

C BLAST HAZARD TESTS

1 Introduction

This section summarizes the blast hazard tests performed at Ballistics Research Laboratory, Aberdeen Proving Ground, on an E49 Filter Unit during March 1965. A detailed discussion of testing is contained in Report No. 18, Blast Hazard Tests[35].

The purpose of the blast hazard testing was to provide experimental data on the potential shock wave damage, or blast hazard, that can occur to the Filter Unit, the

shock wave attenuation through the Filter Unit, and the degree of blast protection required.

Particulate filters were tested for DOP smoke penetration at Edgewood Arsenal both before and after shock tests. Edgewood Arsenal penetration tests used thermally dispersed homogeneous 0.3 μ diameter DOP aerosol in accordance with MIL-STD-282[5]. The maximum allowable penetration specified by Edgewood Arsenal for the particulate filter is 0.03 percent.

2 Test Performance

The measured test pressures at different locations in the Filter Unit were read from oscillograph records. Typical pressure levels, shown on Figure 27, indicate the pressure attenuation and time delay as the pressure wave travels through the precleaner assembly.

The data indicates a pressure attenuation of 50 to 60 percent through the fan, and 30 to 35 percent attenuation in the dust separator and flow control, for a total attenuation of 85 to 90 percent before the pressure wave reaches the particulate filter. The results are contained in Table 14.

The DOP penetration tests were performed after each shock test to determine any increase in penetration at rated flow of 400 cfm.

3 Conclusions

The following conclusions were drawn as a result of the blast hazard tests:

a) The shock waves generated in the APG shock tube provided a more severe test of the Filter Unit than the ideal wave form.

b) Tests of the particulate filter without the precleaner did not provide significant data because of the bombardment of the filter with rust particles and other foreign matter from the shock tube. Therefore, the minimum rupture pressure of the particulate filter media could not be determined.

c) Use of a perforated metal plate ahead of the particulate filter, as tested, provides no improvement in blast resistance.

d) Approximately 90 percent pressure attenuation through the precleaner was achieved during both Filter Unit operating and nonoperating modes.

e) The Filter Unit showed no damage that would significantly degrade its performance to shock pressures of 15 psi.

f) No antiblast closure is required for the specified shock pressure range of 0 through 10 psi.

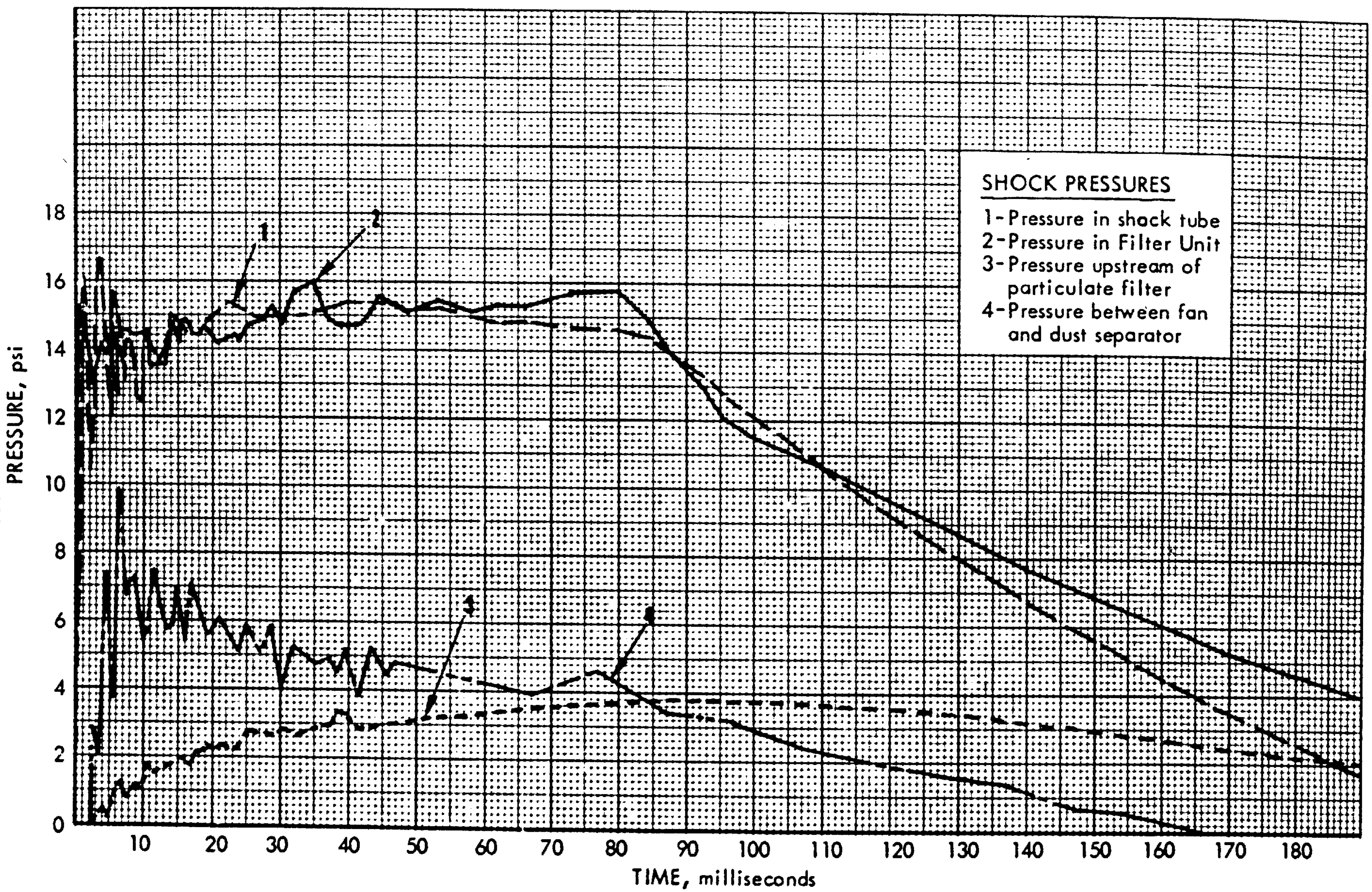


Figure 27. Pressure Attenuation Through E49 Filter Unit at 15.4 psi.

TABLE 14. MAXIMUM PRESSURES AND ATTENUATIONS

Max. Shock Pressure, psi	Max. Pressure At Particulate Filter, psi	Max. Diff. Pressure Across Particulate Filter With Precleaner Installed, psi	Average Attenuation Through Fan, Percent	Average Attenuation Through Precleaner, Percent
2.7	.75	.52	49 ± 20	86 ± 8
3.6	.94	1.24	53 ± 15	86 ± 8
7.3	1.80	1.41	56 ± 8	86 ± 8
9.3	2.22	1.91	59 ± 9	86 ± 5
10.8	2.87	2.15	53 ± 8	90 ± 5
15.4	3.80	3.18	54 ± 14	91 ± 6

Differential pressures across the particulate filter are plotted in Report No. 18[36] for each shock test.

VII RECOMMENDATIONS

A INTRODUCTION

The design and development of the E49 Gas-Particulate Filter Unit successfully proved the positive-pressure collective protection concept for vehicles. The way is now clear to carry on product improvement and application studies for other vehicles.

Through the course of this contract many areas of investigation relating to either product improvement or application became apparent, but were not pursued since they were either beyond the scope of the contract or the time frame did not allow a detailed study. Thus, the following continued effort is recommended.

B PRODUCT IMPROVEMENT

1 Cost Reduction

Perform overall study of materials and processes.

Re-evaluate deep-fording valve .

Study alternate construction methods for gas filter.

Re-evaluate control panel design for use of less expensive components.

2 Performance

Reduce the size or increase the dust capacity of the particulate filter by redesign, including redesign of the spacers presently used.

Study of charcoal retention, to reduce attrition when used in a vibratory environment.

Redesign the E62 precleaner to allow interchanging of major components, thus providing either a negative or positive pressure system.

Redesign the fail-safe sealing system for application to either a negative or positive pressure system.

Improve fines media to materially extend physical life of gas filters in vibratory environments.

3 Weight Reduction

Conduct a weight reduction study of the Filter Unit, to facilitate broader application to waterborne or airborne vehicles, where weight is of prime importance.

4 Shock and Vibration Requirements

Establish realistic shock and vibration acceptance test specifications for the Filter Unit and components.

5 Competitive Procurement

Establish additional qualified sources for specification controlled components such as the fan assembly and pressure switches.

C APPLICATION TO OTHER VEHICLES

Conduct a study of Government needs for vehicle collective protection, including:

1 Vehicle Requirements

Evaluate applicable vehicles to determine need for, and possibility of, using E49 Filter Unit for collective protection.

2 Airflow Rate

Evaluate airflow requirements for vehicle pressurization to determine need for a family of Filter Units with various ratings.

3 Filter Unit Mounting

Evaluate Filter Unit mounting location, including external or internal of crew compartment and vehicle shell.

4 Pressurization Types

Evaluate suction versus positive pressure Filter Units to determine the optimum configuration of components.

VIII ENGINEERING SERVICES

The following sections summarize the engineering services activities during design and development of the E49 Filter Unit.

A RELIABILITY

A Reliability Program was established early in the Feasibility Phase of this contract to assure that reliability goals for the Filter Unit were met.

The reliability goals were established through Failure Mode Analysis, a Reliability Design Review Checklist, and by an Assumptive Predicted Reliability Study. Maintenance Engineering and Quality Assurance programs also influenced the establishment of the reliability goals.

Assuring reliability in Filter Unit design was accomplished by conducting Failure Mode Analysis followup review, Reliability Design Review Checklist followup action, through data feedback from development engineering testing using failure reporting, and through failure analysis and corrective action followup.

The Reliability Program; in conjunction with the Maintainability, Quality Assurance, and Human Factors programs; influenced the design in many areas, including:

1. Fail-safe filter sealing.
2. Self-locking nuts and threaded inserts, to resist loosening under vibration and shock.
3. Fail-safe warning flasher in control panel.
4. Limit switch mounting revision for more precise and easier assembly.

Component reliability life tests were conducted on the E70 deep-fording valve and the pressure switches. Both tests demonstrated the life of these components were in excess of system requirements which are based on:

1. Expected tracked vehicle operational life of 125,000 miles or 12,500 hours (10 miles equals one hour).
2. Filter Unit operation 100 percent of vehicle operation.
3. Deep-fording valve requirements of 81 cycles per 960 hours of Filter Unit operation.

4. Pressure sensing switch requirement of five cycles per one hour of Filter Unit operation.

5. Complete maintenance support.

The E70 deep-fording valve was cycled 50,000 times under static conditions without failure. Derating this test 70 percent because of lack of applied environmental requirements equals 15,000 cycles. This is the equivalent of 177,778 hours of Filter Unit operation.

The pressure switch was tested to 1,372,602 cycles under static conditions without failure. Derating this test 70 percent because of lack of applied environmental requirements equals 411,780 cycles. This is equivalent to 82,356 hours of Filter Unit operation.

A final Substantive Reliability Report, based on accumulated test data from both developmental and reliability tests, is included as Appendix D of this report.

The assumptive reliability study and the reliability substantive test data were used as an aid in determining quantitatively the allocation of replacement parts for maintenance support planning, based on the expected life of Filter Unit components. To complete the reliability program, a Reliability Demonstration Test was also established and conducted to substantiate the assumptive predicted reliability of the Filter Unit. The test was run for a total of 1760 hours or twice the predicted minimum MTBF of 880 hours. There were no failures during the test except for five indicator lamps in the control panel which in no way affected the performance of the Filter Unit. Development test data was collected to aid in substantiating the predicted reliability of the Filter Unit.

The Reliability Demonstration Test was performed on a Filter Unit that was previously used for developmental testing. This testing included a total of 105.5 hours as follows:

- 0.5 hours inspection running time.
- 2.2 hours barometric pressure test.
- 2.4 hours humidity test.
- 1.0 hours pressure drop test.
- 99.4 hours dust test at a concentration of .025 gm/cu ft of AC Coarse Test Dust.

The 105.5 hours development tests were included as a part of the 1760 hours of reliability testing.

The test setup included an exhaust damper to vary the airflow from mean flow (approximately 400 cfm) to max flow or firing mode (flow control valve full open) to min flow (approximately 135 cfm) and return to mean flow. The damper was controlled by an electric timer that cycled the flow every 1.5 hours of operation.

The voltage, amperage, and unit output pressure (1-inch water gauge) measured at the Filter Unit outlet were continuously recorded.

The fan assembly output pressure was measured using a manometer and was manually recorded as availability of personnel allowed.

The test was run on a cyclic basis with the unit operating continuously for 48 hours followed by a two hour shutdown to simulate vehicle mission time. The first maintenance was performed at 500 hours.

The second scheduled maintenance was performed at 1500 hours because the fan assembly is designed to run 1000 hours under static conditions with no environmental conditions applied. However, at 1500 hours no maintenance was required and the test was completed without failure.

B MAINTAINABILITY

A Maintainability Review Checklist was developed, in accordance with EP2, Maintenance Engineering Requirements for CBR Developmental Equipment[15]. Items that are not part of the EP2[15] checklist, but pertained specifically to the development of Filter Unit design, were added to the checklist. Maintainability Reviews, a total of four, were performed after each hardware buildup to determine any deficiencies in design with respect to operation and maintenance.

The Maintainability function was closely coordinated with Development and Product Engineering. Maintainability data was important in modification of the Filter Unit design. The objective was an end item with minimum maintenance, maximum life, quality, reliability, to provide maximum probability of mission success at the lowest cost. Human Factors, Value Analysis, Quality Assurance, and Reliability programs aided the maintainability program.

Maintainability Review No. 1 reviewed the Filter Unit Breadboard Models. Maintainability Review No. 2 reviewed Working Model Filter Units. Maintainability Review No. 3 was the first review of the E49 Filter Unit optimum design. The final review, Maintainability Review No. 4, was a review of the final or Class I design of the E49 Filter Unit.

The four reviews resulted in the following corrective actions:

1. Redesign of the deep-fording valve cover to eliminate rain and water from entering the unit inlet.

2. Limit switch mounting redesigned with nut plates to eliminate the need for a wrench to hold the nuts, which also reduced assembly time and allowed more precise adjustment of switches.

3. Periodic gasket surface cleaning and inspection requirements.

4. Use of AN socket connectors and manifold-type pneumatic connectors for easy disassembly and reassembly.

5. Standardization of fasteners, hardware, and lubricants.

6. Prevention of inadvertent interchange of filters.

7. Self-positioning of components to eliminate damage to system or error in reassembly.

8. Modular design for independent removal of the three major components.

C HUMAN FACTORS

The Human Factors Engineering objective was a comprehensive analysis of the man-machine relationship of the Filter Unit in accordance with the Human Factors Engineering requirements of the contract.

The Human Factors man-machine concept was complicated in the design of the Filter Unit, especially the control panel, since the final configuration of the MBT has not been determined. Thus, the Filter Unit was designed without detailed knowledge of the proposed mounting location or the ambient noise and light conditions in the crew compartment.

Human Engineering was continued throughout the contract on all components. Relationships between the operator and the Filter Unit are listed below:

1. Human Engineering is evidenced in the Filter Unit housing by accessibility of filters, mounting of the filters in the housing, retention of the filters in the housing, and the lifting eyes on the housing.

2. The weight of the gas filter is in accordance with the maximum lifting capacity of one man. The handles on the gas filter were designed in accordance with HEL Standards except that the radius

of the handle is smaller than specified because of space limitation.

3. The handle of the particulate filter was designed in accordance with HEL Standards.

4. The mounting of the precleaner was designed for easy access for maintenance.

5. The control panel was designed in accordance with HEL Standards as evidenced in the displays and the continuity of the panel face. Design of the control panel was determined through coordination with Engineering personnel from ATAC, CRDL, and Donaldson Company.

Control panel display color code and lettering is as follows:

RED - Danger, or a necessity for immediate corrective action.

AMBER - Warning, preliminary to a possible danger condition.

GREEN - Normal system operation.

The power switch is a two segment multiple legend, switch.

The DO NOT FORD display turns amber when the switch is depressed and the fording seal opens. The UNIT ON display is not lighted until the switch is depressed, then it lights green, unless the system circuit breaker is open, and the UNIT ON display lights red.

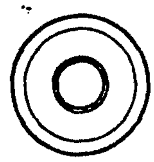
The firing mode switch is a double display, multiple legend switch.

After depressing the FIRING MODE/NOT MAX FLOW switch, the NOT MAX FLOW display lights amber until the flow control is in the maximum open position and then lights green. The FIRING MODE display remains amber until the flow control is in the open position and then lights green.

The MASK indicator is a flashing red light that is activated when the pressure in the crew compartment is below the required level.

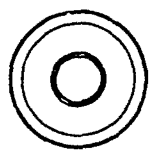
The LIGHT OFF pushbutton switch turns the flashing red MASK light off.

LIGHT OFF



The ALARM OFF pushbutton switch turns the audible alarm off.

ALARM OFF



The last two controls are solenoid-held switches which return to normal when crew compartment pressure returns to normal. After the crew has been warned, the light and audible alarm can be turned off.

The CHANGE FILTER indicator has an amber display that lights whenever the restriction of the particulate and gas filter exceeds the pressure switch setting. This indicates that the particulate filter should be changed after completion of the mission.

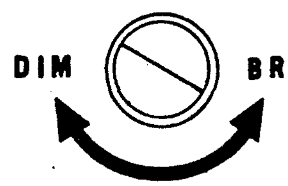
There are four circuit breakers; SYSTEM, FORDING, FLOW, and FAN. Each circuit breaker has an indicator lamp to show breaker actuation.

The appropriate lamp lights when one of the circuit breakers is tripped. The color of each lamp is as follows:

SYSTEM:	Red
FORDING:	Amber
FLOW:	Amber
FAN:	Amber

The SYSTEM indicator lights red since an open system circuit will cut out the normal warning system. The circuit breakers can be reset by depressing.

The DIM/BRIGHT control is a potentiometer which is electrically connected to the circuits

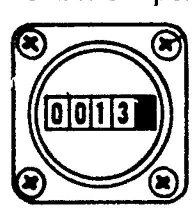


of the UNIT ON, DO NOT FORD, FIRING MODE, and CHANGE FILTER lamps. This control adjusts the intensity of all lights that are not critical warning conditions for crew comfort and blackout conditions.

The PUSH FOR TEST switch is a manually held pushbutton for checking all indi-

cator lamps on the control panel. Depressing the switch indicates all lamps are working.

The hourmeter shows the number of operational hours for maintenance purposes.



The nameplate of the control panel is mounted on a hinged door. Spare light bulbs for the control panel are stored in the nameplate box.

Human Factors Engineering influenced the design of the precleaner assembly. The use of a floating manifold connector for the pressure sensing network assures a positive seal after installation. An overcenter lifting handle allows removal of the precleaner, reducing binding and providing even distribution of the lifting load.

The lifting handles of the gas and particulate filters are also overcenter for even distribution of the lifting load. The weight of the gas filter was minimized so that it would not exceed the maximum HEL recommended weight. Foolproofing of installation of both filters assures that the filters cannot be interchanged during installation.

D VALUE ANALYSIS

Value Analysis is the elimination of unnecessary costs in design, development, purchasing, or production without loss in quality or performance. It assumes that every increment of cost "proportionately contributes to the function of a unit". This program was administered at Donaldson Company by a full-time Value Analyst working with a team of key people in Product Engineering. It is applied through regular meetings with these people in brainstorming sessions and reviews.

Value Analysis has been applied to the Filter Unit at all stages of development and the results of Value Analysis were part of the basic design effort. It was possible to immediately incorporate many of the ideas during this period, because of the early stage of the design. One specific example of value analysis occurring early in the contract involved the deep-fording valve cover. This cover now seals the main Filter Unit air inlet, the dust scavenging outlet, and the atmospheric pressure tap. Originally, each of these openings was to have a separate sealing device. In the Preproduction Model, however, a single cover provides sealing for all three openings.

During the term of this contract, 1066.2 hours were used on Value Analysis. The Value Analyst used the following monitoring sources to aid in identification of poor value areas, to determine alternate methods, and to provide rapid access to background data:

1. Design review.
2. PERT or other control charts.
3. Reliability studies and data.
4. Production procedures.
5. Cost analysis.
6. Special studies.

7. Engineering and military standards.

8. Component engineering.

Table 15 contains a summary of some design changes attributed to Value Analysis and the contemplated savings on future procurement. The table also shows improvements in performance, reliability, and maintainability attributed to Value Analysis. There are additional areas where cost savings could be realized. The control panel should undergo a detailed cost analysis since the late development did not permit detailed cost reduction study.

E QUALITY ASSURANCE

1 Introduction

A Quality Assurance program was established to provide a sound quality control system conforming with the requirements of MIL-Q-9858[16]. The prime objectives of this program were to assure that the 12 Preproduction Models manufactured under this contract conform to the requirements of the Class I drawings and specifications and to provide a method of maintaining the same level of control for future production.

Quality control was exercised through incoming inspection of parts and materials used in fabrication of the end item and through inprocess inspection of parts fabricated inhouse. To establish this control, it was necessary to fabricate inspection aid test equipment and develop installation, operating, and maintenance instructions for this equipment. The following paragraphs describe the various controls exercised in the performance of the Quality Assurance Program.

2 Performance Checks

Inspection aid test equipment was designed and prototype test equipment fabricated to facilitate performance testing in accordance with purchase description requirements. The performance criteria and test methods used to assure that the equipment meets the criteria are as follows.

a. E49 Filter Unit

The Filter Unit purchase description specifies an operational checkout of the unit using a standard E67 control panel. This check insures that the unit evidence proper performance by meeting the maximum air delivery requirement of 400 cfm against 9.0 inches of water pressure and the airflow regulating function by delivering a maximum of 135 cfm of air against 1.5 ± 0.1 inches of water pressure. A transition duct at the air outlet, containing pressure measuring devices and a conical type airflow control, provided the necessary inspection equipment.

TABLE 15. VALUE ANALYSIS SAVINGS

Part Number	Description	Savings/1500 Units	Change	Improvement
B5-19-3203	Pad, Shock	$ 1,080.00	Remove 0.12 x 45° chamfer two places.	Reliability
C5-19-3211	Spacer	11,250.00	Remove irridite note. Irridite in next assembly.	
E5-19-3232	Cover, Cast & Machine	900.00	Remove two MS12078 helicoils and tapped holes.	Maintainability
C5-19-3233	Handle	600.00	Change material from stainless steel to cadmium plated steel.	
C5-19-3117	Tube Disconnect, Lower	2,010.00	Remove one 0.255-inch diameter hole, both 0.199-inch diameter holes, add counter bore to remaining 0.255-inch diameter hole. Make from extrusion.	Maintainability
B5-19-3116	Disconnect Assembly	480.00	Remove 9609A167 tube. Place Y-connection downstream. Epoxy tube joints instead of weld.	Maintainability
C5-19-3247	Tube, Disconnect Upper	750.00	Remove two 0.184-inch diameter holes, counter bore two 0.255-inch diameter and make from an extrusion.	Maintainability
B5-19-3245	Disconnect Assembly	1,920.00	Remove two 9609A161 pins and epoxy tube joints instead of weld.	
B5-19-3248	Pin Disconnect	1,260.00	Remove	
B5-19-3144	Bracket, Disconnect	720.00	Combine with 9609A151.	Maintainability
C5-19-3161	Channel, Hinge & Extrusion	570.00	Remove center slot.	Performance
B5-19-3324	Spacer	1,500.00	Change material from stainless steel to cadmium plated steel.	

TABLE 15. VALUE ANALYSIS SAVINGS (continued)

Part Number	Description	Savings/1500 Units	Change	Improvement
E5-19-3263	Body Assembly	$ 105.00	Add minimum grind note.	
9613A63	Actuator	395.00	Replace with pin.	Reliability
B5-19-3279	Hub	3,000.00	Change material from stainless steel to cadmium plated steel.	
E5-19-3100	Screws, Nuts & Bolts	6,000.00	Material change from stainless steel to cadmium plated steel.	
B5-19-3149	Pin, Pivot (Ret. mech)	1,000.00	Change finish from 32 microinch to 64 microinch.	
B5-19-3249	Gasket, Disconnect	15.00	Remove 0.187-inch diameter holes.	Reliability
D5-19-3293	Casting, Body (fording valve)	795.00	Remove impregnation.	
B5-19-3307	Plate, Gasket (fording valve)	105.00	Change material from stainless steel to cadmium plated steel.	
B5-19-3275	Clamp, Collar (flow control)	1,050.00	Change material from stainless steel to cadmium plated steel plus change to standard bar stock material.	
C5-19-3233	Handle, Precleaner	100.00	Change precleaner handle and mounting arrangement.	Maintainability
C5-19-3107	Retainer, Filter	3,000.00	Remove electro-film lubricant.	
NAS43DD	Tubing, Leg	1,000.00	Replace with standard part number NAS43DD.	
NAS43DD	Spacer	2,018.00	Replace with standard part number NAS43DD.	

TABLE 15. VALUE ANALYSIS SAVINGS (continued)

Part Number	Description	Savings/1500 Units	Change	Improvement
B5-19-3113	Nut, Shoulder (retaining mech)	$ 9,126.00	Replace special slotted nut with standard hex shoulder nut.	Maintainability
C5-19-3323	Tubing, Control	6,100.00	Mark tubing by lots instead of kit.	Maintainability
B5-19-3325	Assembly, Adapter	1,875.00	Replace with hose coupling.	Maintainability
B5-19-3165	Pad, Corner	45.00	Change dimensioning to conform to standard aluminum bar stock.	
B5-19-3153	Tube, Pressure Sensing	1,0[illegible].00	Rearrange pressure sensing tube.	Maintainability
D5-19-3297	Cap Assembly	1,460.00	Lock nut replaces nut and screw formerly used.	Maintainability Reliability
	Electrical Wiring	9,000.00	Change from plain wire with shrinkable markers to premarked wire.	Maintainability

b. E62 Precleaner Assembly

The precleaner purchase description specifies performance checks of minimum and maximum air delivery, pressure regulation, and filter restriction sensing. The pressure regulation check, in effect, checks the proper operation of all control components on the precleaner.

A special black box test apparatus was designed to facilitate inspection. This device requires that the precleaner be inspected in a special test housing which connects to a power source, air regulating and pressurizing equipment, and to a display and control panel which allows step-by-step testing and status display for the various requirements.

The following functions are checked sequentially:

Minimum airflow (and current draw)
Maximum airflow (and current draw)
Low Pressure circuit (at 1.3 inches of water)
Normal Pressure circuit (at 1.75 inches of water)
Overpressure circuit (at 2.2 inches of water)
Pressure switch settings

This test device, although designed for acceptance testing, could serve a useful function for trouble isolation in maintenance depots since malfunctions are quickly isolated when performing the check sequence.

c. E67 Control Panel

The control panel purchase description specifies performance tests of each control, warning, and indicating circuit in the control panel. A black box test device was designed to facilitate quality control checking. The test device connects to the electrical receptacle on the control panel and to a 27.5 v.d.c. power source and negative ground. The test device simulates all operating conditions of the precleaner and pressure sensing network and the control panel responds as it would in the operating mode.

The following items are checked in order; UNIT ON switch indicator circuit, PUSH FOR TEST switch circuit and panel lamps, DO NOT FORD indicator circuit, PUSH FOR FIRING switch circuit and FIRING MODE and NOT MAX FLOW indicating circuits, the normal pressure circuit, MASK indicating circuit, audible warning circuit, CHANGE FILTER warning circuit, elapsed-time recording circuit, audio and visual warning disconnect circuits, DIM/BR rheostat circuit, FORDING circuit breaker operation, FLOW

circuit breaker operation, FAN circuit breaker circuit, SYSTEM circuit breaker operation, and the unit shut-off circuit.

This test device would serve a useful function in trouble isolation for maintenance purposes.

d. E70 Deep-Fording Valve

Performance checks of the deep-fording valve purchase description cover travel speed, travel limits, and operation after extreme low temperature exposure. The latter requirement specifies saturation at $-65^{\circ}F$ prior to performing the first two checks of travel.

The device for checking travel requirements connects to a dc power source and an electronic timer, which initiates opening and closing of the valve and displays the proper operating status.

The fixture initiates the opening action of the fording valve cover while timing the opening sequence. Indicators display the proper operation during simulation of the fan and control panel operation. The fully open position and valve motor deactuation are also displayed by the test panel. The proper indications are repeated for the valve closing sequence.

This test device serves a secondary function in assembly for checking the proper setting of the valve limit switches. This could also be used in maintenance for checking the proper setting of switches after maintenance has been performed.

e. Housing Assembly

Since housing leaks are a critical factor, a housing leak test device was designed to check the purchase description requirements for leak proof construction. This device allows testing of the housing under positive internal pressure to detect any pin hole leaks through housing seams and fail-safe channels.

f. Fan Checks

Purchase description performance requirements specify air delivery, efficiency, and slope checks of the fan in accordance with AMCA Bulletin 210[39]. A sophisticated air chamber, with a series of baffled chambers for even air distribution, was designed to check these requirements. The following items are checked in order:

Fan actuation

Current draw

Operating temperature
Fan output pressure
Air delivery
Repeat above readings at 25 cfm increments
down to 135 cfm air delivery
Establish performance curves
Establish fan performance
Establish fan efficiency

g. E59 Particulate Filter

The particulate filter purchase description specifies the requirements for resistance to airflow, DOP penetration, dust capacity, and bonding strength. A fixture was built for dust capacity testing using a modified AFI dust feeder with an inlet duct for even dust loading and a downstream plenum chamber for flow control and sampling. DOP and resistance testing was performed using the standard fixture used in regular production testing and an adapter fixture was designed to mate with Government test equipment. The bonding strength test was performed on filters which had been destructively tested for dust capacity.

h. E61 Gas Filter

The gas filter purchase description specifies the requirements for airflow resistance and phosgene gas life after vibration. Since the phosgene testing is performed by the Government, an adapter for the E61 Gas Filter was designed and provided to the Government to mate with their test equipment.

Operating and maintenance manuals were prepared for each of the above test equipments. The 12 Preproduction Filter Units and components were checked in accordance with test instructions. These tests were reviewed by Government QA personnel assigned to the Chicago Procurement Office (reference Appendix I) and all test data was recorded and is on file at Donaldson Company.

3 Environmental Resistance

The majority of environmental testing of the Filter Unit and components was performed and certified by an independent test agency. The tests were monitored by Donaldson Company and Government designated QA personnel to assure that all tests were in accordance with Appendix B1 of the contract and to see that the tests were properly documented. Complete test data is on file at Donaldson Company, Inc. Section VI A contains the details of all environmental resistance checks.

4 Material and Dimensional Checks

Exacting Quality Control was exercised during incoming inspection to assure that all materials and parts conformed to the requirements of the Class I drawings. One hundred percent inspection was made on all components except for Military Standard items where certification by the manufacturer of performance and quality was mandatory. All inspection results were recorded and are on file in accordance with the established Quality Control requirements. Subcontractor's and supplier's certifications of conformance have been received and are on file. Also, the Chicago Procurement District Area Resident Inspector inspected three each of all parts, sub-assemblies, and final assemblies, (reference Appendix I).

F DRAWINGS

Drawings were generated throughout the design and development of the Filter Unit. Layout drawings of proposed concepts were made prior to systems selection. Layout drawings formed the basis for coordination drawings, after design selection. Coordination drawings were then updated to Class II status. After Engineering Development Tests, the Class II drawings were updated to Class I format.

During the Feasibility Phase of the program, approximately 55 sketches and layouts were completed. These layouts were of system concepts, filter arrangements, air supply modules, deep-fording valves, airflow control valves, dust separators, retaining mechanisms, particulate filters, and gas filters. From these sketches and layouts, approximately 90 detailed drawings were completed of the most promising concepts, and a breadboard model was built.

Tests were run on the breadboard model by Donaldson Company. After test evaluation, it was decided by Edgewood Arsenal, ATAC, and Donaldson Company that two overall design approaches would be followed. The one approach, designated E49 Filter Unit, contained all components, except the control panel, within one housing. The other approach, designated E50 Filter Unit was similar, except the air supply module could be separated from the filter module. Complete layouts of the E49 and E50 Filter Units were made, along with detail layouts of sub-asser .lies. Approximately 190 detail drawings and sub-assemblies were completed on Donaldson Company format. These drawings contained sufficient information to fabricate the four working models. Both Edgewood Arsenal and Donaldson Company ran performance tests on these units.

Edgewood Arsenal decided that the E49 Filter Unit would be the optimum design. Approximately 230 Class II drawings were made in accordance with MIL-D-70327[17]. These drawings incorporated design changes that were the outcome of performance tests and design review meetings. Four Optimum Development Models were built from these Class II drawings. These Optimum Development Models were used in complete environmental and performance tests as specified in the Statement of Work. As a result of these tests and another design review meeting, the drawings were again updated. Government numbers were assigned and DLs completed. The Class I drawings and draft PD's were then released to fabricate the 12 Preproduction Models.

Close liaison was maintained between Donaldson Company Engineering and Production during fabrication of the Preproduction Models. Drawing errors and modifications were found and corrected during this period. All notations in the drawing revision blocks were removed and the drawings dated September 30, 1965. Three Government representatives signed and approved the Class I drawings during the week of September 27, 1965. The tracings were then microfilmed and five sets of aperture cards were made, along with one set of tabulating cards. These cards, along with the original tracings, were then sent to Edgewood Arsenal.

G PURCHASE DESCRIPTIONS

Purchase Descriptions (PDs) for the E49 Filter Unit were prepared in accordance with PD 197-54-820[18], dated 8 January 1962, and Defense Standardization Manual M200[19], dated 3 September 1962. The following PDs were prepared:

PD 197-54-936 Fan, Mixed-Flow, 440 cfm, 27.5 vdc

PD 197-54-937 Filter, Particulate, 400 cfm, E59

PD 197-54-938 Filter, Gas, 400 cfm, E61

PD 197-54-940 Precleaner, 440 cfm, E62

PD 197-54-941 Filter Unit, Gas-Particulate, Tank EMD, 400 cfm, E49

PD 197-54-942 Valve Assembly, Deep-Fording, E70

PD 197-54-943 Control Panel, Gas-Particulate Filter Unit, E67

PD 197-54-944 Housing Assembly, E49 Gas-Particulate Filter Unit

These PDs were shipped to the Government on 15 October 1965.

Work on PDs began in June, 1964, when a preliminary draft of the fan PD was prepared. On 15-16 July 1964, a coordination meeting was held between personnel of Donaldson Company and Edgewood Arsenal to discuss documentation. It was decided to write PDs for all major components of the Filter Unit that would be stocked as spare parts and those items which required detailed test methods to prove performance. It was thought at that time that a PD would be written for the dust separator/airflow control valve.

During the period of November 1964 to February 1965, work continued on the PDs. A meeting was held 10-12 February 1965 and the PDs were discussed in detail. At that time, the format, general requirements, and the philosophy of PDs was covered. Since the PD was to be a control on production, it would furnish a basis for inspection, and specify the requirements for the Filter Unit and its components.

It was thought that a PD would be written for every spare part to be stocked in the field, provided the part was stocked as a complete unit or subassembly. The PD would then specify the required performance levels and the tests to insure these levels.

The necessity for writing a PD for the dust separator/airflow control valve was discussed since it would be part of the precleaner assembly and has a high reliability. It was later decided (18 February 1965, Edgewood Arsenal) not to write a PD for this item.

Work continued on the PDs during the period of February to May 1965. The third and last coordination meeting for the purpose of discussing documentation was held 26-28 May 1965 at Edgewood Arsenal. It was decided that the Filter Unit Assembly PD would be the overall control for all the component PDs. It would include a general operational test while the detailed tests and procedures would be specified in the component PDs.

PD development during the period of June to September 1965 was coordinated with Edgewood Arsenal. All the PDs were submitted for final approval during July and August 1965. The PDs were published October, 1965 after incorporation of Government comments.

H MAINTENANCE DOCUMENTS

Maintenance documents were prepared in accordance with EP2[15]. The documents included the Maintenance Support Plan (MSP), Maintainability Reviews, and Preliminary Operating and Maintenance Manuals (POMMs) which were later updated to Maintenance Package Manuals (MPs). The training aids and lesson plans are a part of Maintenance Documents and are described in paragraph I.

MSP 3-4240-250 was prepared February 1965, in accordance with Appendix III of EP2[15], This plan outlined the maintenance concept, end item application, major and secondary end items, in-process reviews, maintenance evaluation, equipment publications, support equipment requirements, personnel and training requirements, technical assistance, maintenance float requirements, and repair parts provisioning. The MSP states the maintenance concept and outlines the maintenance support requirements for equipment when issued to the field. The MSP was updated and published in November 1965 as MSP 3-4240-250-2.

POMMs were prepared in accordance with Part One of EP2[15]. POMMs furnish test personnel with the necessary information to maintain and operate the E49 Filter Unit from the early developmental phases through the engineering test phase. Three separate POMMs were prepared; POMM 4240-250-12, POMM 4240-250-25P, and POMM 4240-250-35.

Intensive work began on the POMMs in August 1964, They were submitted for Government review in November 1964 and, after approval, they were published. In December 1964, 100 copies of each POMM were shipped to Edgewood Arsenal.

Updating the POMMs began in June 1965. Government and Donaldson Company personnel checked maintenance instructions in the POMMs against actual disassembly procedures to determine possible changes.

The most extensive changes were made in POMM 4240-250-12, because of the new control panel design. The new control panel design required that all wiring schematics, maintenance instructions, and trouble shooting had to be revised.

The POMMs were updated to MPs and designated as MP 3-4240-250-12, MP 3-4240-250-25P, and MP 3-4240-250-35. The MPs were printed and 100 copies of each were shipped to the Government in October 1965. Fifteen copies of each were included with the Technical Data Package, and 24 copies with the 12 E49 Filter Units.

I TRAINING

A training course, entitled Technical Training Course, was provided for the Filter Unit. The course was prepared in accordance with MEP 40[20], Requirements for New Equipment Training for Edgewood Arsenal Developmental Equipment. The course objective is familiarizing instructors and maintenance personnel with the operation and maintenance of the Filter Unit.

It was decided, through coordination with Government personnel, that the course would not follow the lines of the Technical Familiarization Course (TFC) or the New Equipment Training Course (NETC). The principal reason for this decision was the indefinite status

of the MBT. As a result, the Filter Unit was designed as a component development with no Engineering Test/Service Test (ET/ST). With ET/ST, orientation of service test personnel was not necessary. This also eliminated the need for a TFC Course. It was anticipated that this course would be updated when the MBT system was finalized. The course would then be designed for specific objectives, such as TFC, or NETC. The course consists of a Program of Instruction (POI) which coordinates the Lesson Plans (LPs) for each hour of instruction. To supplement the LPs, 43 slides and 17 flip charts were also prepared.

Preparation of the course began in May, 1965, and its development was closely coordinated with Government training personnel. The Training Course was approved with the understanding that changes would be made before final submittance. The Course and Training Aids were shipped in October, 1965.

The Course is designed for 29 hours of instruction and is divided into two annexes. The first Annex is for the familiarization of operators and organizational maintenance personnel with the Filter Unit and teaching them the simpler maintenance tasks. Each LP within the Annex is a unit of instruction and may require from one to two hours of classroom time. The LPs have been designed to cover a single topic in each unit of instruction. A LP may take more than one hour in order to cover the topic. The Annex assumes that the student has no prior knowledge of the Filter Unit.

The second Annex is concerned with direct, general support, and depot maintenance. The LPs discuss more complicated maintenance, and usually require more time than the first Annex.

The training aids were designed as an integral part of the training course. The slides first describe the Filter Unit, next the component parts, and finally, the method of operation.

The charts are exploded views, pictorial or block diagrams. They are used to aid the instructor in demonstrating maintenance steps or trouble shooting of electrical circuits.

J PACKAGING AND PACKING

Packaging and packing for the Filter Unit and repair components was developed in accordance with MIL-P-116[21] and TM 38-230[22], The proposed packaging was used to ship units and components to Edgewood Arsenal. Government personnel conducted tests in accordance with CBR Agency Test Manual 70-1[23], packaged units and components to determine the adequacy of the packaging and packing.

After testing in accordance with the CBR Agency Test Manual 70-1[23], coordination meetings were held between Donaldson Company and the Government to upgrade packaging requirements to Level A which is adequate for initial and worldwide distribution, shipping, and storage conditions and furnishes a higher degree of protection than Levels B and C. The use of Level B requires a prior knowledge of the shipping and storage conditions that will be encountered. Level C preservation and packaging requires shipment from supplier to receiver for immediate usage or storage under controlled humidity.

Packaging and packing instructions, including a sketch of the finished packages, were prepared for the Filter Unit. Packaging and packing data sheets, with illustrations, were prepared for the E70 deep-fording valve, E67 control panel, E59 400 cfm particulate filter, E62 400 cfm precleaner, E61 gas filter, the 440 cfm mixed-flow fan, and the filter unit housing. A data sheet was also prepared for recommended packaging of repair kits.

K PRODUCT ENGINEERING

Product Engineering for this contract included the functions of Product Design, Industrial Engineer, manufacturing, purchasing, Development Engineering, Maintenance Engineering, Value Analysis, Human Factors, Reliability Engineering, and Quality Assurance. The entire design was reviewed and each part analyzed. Feedback from these functions was evaluated and incorporated into the design. The objectives were design simplification, parts standardization, fabrication technique simplification, reducing costs and tooling, improved reliability and maintenance features, and correction of deficiencies. This synopsis covers changes made in fabrication methods rather than other aspects of Product Engineering. It is assumed that these changes were made primarily for facilitating manufacture of the Filter Unit.

A summary of the changes is listed in Table 16. The list does not include changes made solely as a result of Value Analysis, Maintainability, Reliability or Human Factors. These changes are covered in other sections.

TABLE 16. PRODUCT ENGINEERING DESIGN CHANGES

Part	Change	Reason
Retainer, Filter	Change from formed part to extrusion. Revise end cuts.	Reduce cost and improve product.
Nut, Shoulder	Change from round slotted nut to hex nut.	Reduce cost, eliminate special tool. Facilitate assembly.
Pin, Swing	Change from shouldered to straight.	Reduce cost.
Filter Unit Housing	Change design to facilitate spot welding. Change guides to act as stiffeners. Use extrusions wherever possible.	Reduce cost, improve unit.
Body	Change from three pieces to one formed part.	Reduce cost, increase reliability.
Rail, Guide	Change from machined part to extrusion.	Reduce cost.
Block, Swivel	Change design to extruded part.	Reduce cost.
Rim, Mounting	Reduce number of parts.	Facilitate welding. Increase reliability.
Shield, Tube	Change design to facilitate spot welding.	Reduce cost.
Channel, Fail-Safe	Change from standard to special extruded channel.	Facilitate welding. Increase reliability.
Channel Rim	Change from formed to extruded part.	Reduce cost. Facilitate welding.
Filter, Gas	Redesign to provide track to install air chamber into housing.	Reduce cost.
Actuator Body	Remove two tapped holes, add drilled hole, change material.	Reduce cost.

IX CONTROL OF PERFORMANCE

Performance of this contract was controlled both by constant coordination with Government agencies on technical matters and by close internal control of labor hour and direct costs. The various techniques used are discussed in the following paragraphs.

A PERFORMANCE EVALUATION & REVIEW TECHNIQUE (PERT)

PERT time networks, prepared before starting contract effort, were maintained throughout contract performance. From the overall PERT network, which covered the entire contract, segments covering the immediately upcoming period were expanded to show in more detail the required steps. These expanded PERT networks covered 6-month periods.

The PERT network was initially run on a computer with biweekly printouts. After a 6-month trial, the cost and upkeep of this type of printout was analyzed. It was decided that the network could be efficiently controlled manually. Accordingly, Modification No. 2 eliminated the requirement for computer printout of the PERT network. This change resulted in a substantial cost savings without jeopardizing the usefulness of this management tool.

B COST AND HOUR REPORTING

A system of cost and hour reporting was established for this contract through which costs attributable to various parts of the contract work could be continually tabulated and summarized. The system allowed separation of types of labor (i.e., Project Engineers, Draftsmen, Technicians) from the type of work involved (i.e., Engineering Development, Class I drawings, Packaging) and the specific item of hardware involved (Precleaner, Particulate Filter, Control Panel). Through use of electronic data processing equipment, all combinations of the different categories of labor, work type, and product could be sorted and rearranged for management analysis.

C WEEKLY MEETINGS AND REPORTS

The above management tools - PERT and Cost and Hour Reports - were used in conjunction with meetings of key technical personnel on a weekly basis. The results of each weekly meeting were forwarded to Edgewood Arsenal to provide an up-to-date review of contract status. Each of the weekly meeting reports included a section relating to current schedule status relative to the current PERT network. Schedule status was presented in terms of events completed, events due next week, and events overdue. Use of this method of reporting proved extremely valuable in providing a timely written record of results obtained as well as anticipated problem areas, allowing better communication between the parties involved.

D STATUS AND FISCAL REPORTS

Status and Fiscal Reports, SMUEA Form 3-9, were submitted monthly to the Contracting Officer. These reports were the primary vehicle for coordination of financial status. Each month the expenditures and commitments in both hours and dollars for that period as well as the cumulative dollar total were presented, comparing these figures against the available funds. An estimate for the next period was also included in the fiscal record. The report also provided the opportunity for indications of schedule status, fund adequacy, and an overall general appraisal.

E LEVEL OF EFFORT REPORTS

Contract DA-18-035-AMC-100(A) was a level-of-effort type contract rather than a job type. Thus, the number of hours applied by various categories of labor were of importance. Each month a report was supplied the Contracting Officer denoting, by categories of labor, the hours expended the preceding month, the cumulative hours expended, and the originally estimated hours.

X CONTRACT END ITEMS

The following documentation and hardware were furnished to the Government in fulfillment of Contract DA-18-035-AMC-100(A).

A DOCUMENTATION

1 Reports

Weekly Meeting Reports No. 1 through 104

Progress Reports No. 1 through 19 (includes Design Study Report and Feasibility Study Report)

Assumptive Reliability Report

Failure Mode Analysis Report

Maintainability Reviews (4)

Reliability Reviews (3)

Computerized PERT Printouts

Final Report

2 Drawings

Coordination Drawings

Class II Drawings of Filter Unit, E49, per MIL-D-70327[17]

Class II Drawings of Filter Unit, E50, per MIL-D-70327[17]

Class I Drawings of Filter Unit, E49, per MIL-D-70327[17]

Drawing Reductions and Microfilm

3 Other

POMM 4240-250-12 Preliminary Operating and Organizational Maintenance Manual for Filter Unit, E49

POMM 4240-250-35 Preliminary Direct Support, General Support & Depot Maintenance Manual

POMM 4240-250-25P Preliminary Organizational, Field and Depot Repair Parts, Special Tools and Equipment List for Filter Unit, E49

Operating Procedures for Filter Units E49 and E50; Working Models of the Most Promising Designs

MP 3-4240-250-12 Operating and Organizational Maintenance Manual for Filter Unit, E49

MP 3-4240-250-35 Direct Support, General Support & Depot Maintenance Manual

MP 3-4240-250-25P Organizational, Field and Depot Repair Parts, Special Tools and Equipment List for Filter Unit, E49

Inspection Aid Operating Manuals (9)

Draft Purchase Descriptions (8)

Lesson Plans and Training Aids

Interim Technical Data Package

Technical Data Package

PERT Networks, revised as required

B HARDWARE

One (1) Working Model, Filter Unit, E49, with Control Panel

One (1) Working Model, Filter Unit, E50, with Control Panel

One (1) Gas Pack, GP7 (Gas Filter, E61, preliminary design)

Ten (10) Gas Filters, E61 Vertical (9606A94)(two retained by Contractor)

Ten (10) Gas Filters, E60 Horizontal (9606A109) (two retained by Contractor)

Twenty (20) Particulate Filters, E59

Three (3) Filter Units, Gas-Particulate, Tank, EMD, 400 cfm, E49 (Optimum Design Development Models)

Twelve (12) Filter Unit, Gas-Particulate, Tank, EMD, 400 cfm, E49 (from Class I drawings and purchase description; 6 with mounting flanges, 6 without)

Nine (9) Assorted Inspection Aids:

- Fan Test Fixture
- Deep-Fording Valve Test Fixture
- Particulate Filter DOP and Resistance Adapter
- Particulate Filter Dust Loading Fixture
- Gas Filter Phosgene and Resistance Adapter
- Housing Leak Test Fixture
- Control Panel Test Fixture
- Precleaner Test Fixture
- Filter Unit Test Fixture

XI CONTRACT COORDINATION

A GENERAL

Development of E49 Filter Units, components, and related equipment under this contract was accomplished through close coordination and cooperation with various Government agencies, the principal facility being Edgewood Arsenal. The Government technical representative at Edgewood Arsenal, functioning as Contract Project Officer, was Mr. Frank Ort from 25 September 1963 to 9 June 1964 and Mr. Gilbert Appel from 9 June 1964 through contract completion. Mr. E.W. Bankert was the Contracting Officer. Engineering service functions were coordinated through Mr. Walter Linkous of the Directorate of Engineering and Industrial Services, Edgewood Arsenal.

B COORDINATION MEETINGS

The majority of contract coordination meetings involved Edgewood Arsenal - either at the Arsenal or at Donaldson Company. In addition to Edgewood Arsenal, however, frequent contact was necessary with Army Tank-Automotive Center regarding integration of the Filter Unit into the proposed vehicle. Contacts were also made with U.S. Army Engineering Research and Development Laboratories, Fort Belvoir, Virginia and the Signal Test Branch at Milwaukee, Wisconsin. Appendix E lists the pertinent meetings under this contract.

C CONTRACT TIMING

Initially, this contract was established on the following time schedule:

	Feasibility Studies Program	Original Tentative Completion Date
Phase I	Feasibility and design studies, fabrication and evaluation testing of Working Models.	3Q CY 1964
	Development Program	
Phase II	Fabrication and testing of R & D Prototypes and Pre-Production Models	4Q CY 1964
Phase III	MBT integration and ET/ST tests completed	4Q CY 1965
Phase IV	Retrofit of systems and finalization of Engineering drawings and documentation	1Q CY 1966
Phase V	Production study	1Q CY 1966

These dates were established to conform with the MBT time schedule. As the contract progressed, it became evident that the extremely tight initial schedule could be extended in accordance with the MBT schedule. Phase I, the Feasibility Phase, was allowed to extend to 27 December 1964 - 3 months past its originally scheduled date. Phase II, which

was originally scheduled for 3 months, was allowed to extend for 10 months because of additions to the scope of the contract such as the Antiblast Closure Study and redirection of development caused by unavailability of an MBT. This contract has covered 24 months, beginning 25 September 1963 and ending 30 September 1965, with 60 days allowed for preparation of this Final Comprehensive Report.

D CONTRACT MODIFICATIONS

The original contract was modified eight times through supplemental agreements. The modifications are listed below with the primary reason for modification.

Modification No.	Date	Purpose
1	27 Nov 63	Change report distribution.
2	9 Mar 64	Delete PERT network computer printout.
3	13 May 64	Change test requirements. Change space allocation.
4	18 Nov 64	Add incremental funding
5	18 Jan 65	Add Antiblast Closure Study
6	28 Apr 65	Update provisional overhead rates.
7	1 June 65	Extend funded time to 31 Aug 65 following partial termination which essentially eliminated Phases III, IV, V.
8	7 Sep 65	Extend time to 30 November 1965.

Modification No. 7 was made for the convenience of the Government because of the unknown status of the MBT. The partial termination, effective 18 May 1965, eliminated portions of the planned effort in Phases III, IV, and V. It did allow, however, completion of all documentation, except for the Production Study Report, so that the E49 Gas-Particulate Filter Unit could be presented to the Military as an end-item component complete with Class I drawings, purchase descriptions, operating and maintenance manuals, training program, and related documentation.

E LEVEL-OF-EFFORT

Contract DA-18-035-AMC-100(A) was a level-of-effort contract. A progress report was submitted each month along with other financial reports comparing the hours spent that month and cumulative hours in each job category against the originally estimated amount.

Because of changes in contract scope and partial termination, the final hours - by mix and total - did not match the original estimate. The final figures are shown in Table 17.

TABLE 17

LEVEL-OF-EFFORT

Category	Hours Expended Through 30 Oct 65	Originally Estimated Hours
Acoustic Engineer	31.5	440
Chemist	1567.5	2800
Designer	6313.5	2059
Draftsmen	7673.4	9160
Field Representative	2.5	1360
Inspector	122.5	2350
Lab Technician	15913.0	12063
Lead Draftsman	3878.2	3260
Manufacturing Hourly	5368.0	9823
Program Manager	3589.5	5560
Project Engineer or Industrial Engineer	9570.4	13865
Technical Writer	7271.9	6564
Technician	5963.6	2280
Value Analysis Engineer	1066.2	2344
TOTALS	68331.7	73928

APPENDIX B1 16 March 1964

STATEMENT OF WORK

Contract DA18-035-AMC-100(A)

PROPOSED TEST REQUIREMENTS

1. Non-operating Conditions

a. Vibration - The unit shall be vibrated according to MIL-STD-810 (USAF) dated 14 June 1962, Method 514, Table 514-1, under Equipment Class 5, Ground Vehicles, with the exception as noted herein.

The unit shall withstand 5 g $^{+0.5}_{-0.0}$ vertical vibration sweeping the range of 15 to 300 cps at a cycling rate of 7.5 min. (Ref. Figure 514-9). The unit shall be tested for 2 hr. at ambient temperature, for 1 hr. at -65°F and for 1 hr. at + 155°F. The unit shall be subjected to the same sequence of tests in both the longitudinal and traverse directions except that the input shall be reduced to 2.5 g $^{+0.5}_{-0.0}$.

b. Shock - Transportation Shock - The unit shall withstand shock tests as specified in MIL-STD-810 (USAF) dated 14 June 1962, Method 516, Procedure II.

c. Humidity - The exposure of the unit to humidity per MIL-STD-810 (USAF) dated 14 June 1962, Method 507, Procedure I shall not produce excessive deterioration in over-all performance.

d. Salt Fog Test - The unit shall successfully withstand the salt fog exposure prescribed in MIL-STD-810 (USAF) Method 509.

2. Operating Conditions

a. Vibration - The unit shall be vibrated according to MIL-STD-810 (USAF) dated 14 June 1962, Method 514, Table 514-1 under Equipment Class 5, Ground Vehicles, Curve B, with the following exception. The unit shall be vibrated for 4 hr. in each of 3 directions; vertical, longitudinal and transverse; sweeping the frequency range of 15 to 300 cps at a cycling rate of 7.5 min. (Ref. Figure 514-9) at ambient conditions.

b. Vehicle Shock - The unit shall withstand shock per MIL-STD-810 (USAF) dated 14 June 1962, Method 516, Procedure I.

c. Humidity - The unit shall operate satisfactorily when subjected to 100 percent humidity at 125°F for a period of 2 hr.

d. Barometric Pressure - The unit shall operate satisfactorily when tested at an equivalent of 10,000 feet (20.58" Hg) by the method prescribed in MIL-STD-810 (USAF), Method 500, Procedure I.

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APPENDIX B
E49 GAS-PARTICULATE FILTER UNIT AND COMPONENT DEVELOPMENT TEST PLAN

A INTRODUCTION

The series of development tests outlined in this plan are intended to prove the design and performance of the E49 400 cfm EMD Tank Gas-Particulate Filter Unit and components in accordance with the specified requirements of Contract DA-18-035-AMC-100(A).

B GENERAL TEST PROCEDURES

The Filter Unit will be subjected to the development tests in accordance with specified procedures.

1 Unit Tests

Shock in accordance with Appendix B1 (Contract DA-18-035-AMC-100(A)).
Vibration in accordance with Appendix B1.
Radio noise interference.
Humidity in accordance with Appendix B1.
Barometric Pressure in accordance with Appendix B1.
Airflow vs pressure drop.
Maximum - minimum flow.
Dust removal efficiency at 200 and 400 cfm.
Dust capacity.

In addition to tests on the complete Filter Unit, separate development tests will be performed on specified individual components.

2 Component Tests

a Fan Assembly

Radio noise interference.
Airflow vs static pressure.
Noise level.
Airflow vs electrical input.
Airflow vs impeller speed.
Impeller erosion.
Continuous operation at elevated temperature.

b Dust Separator

Airflow vs pressure drop.

c Particulate Filter

Airflow vs pressure drop.

Efficiency 0.3 micron mean diameter particle.

d Gas Filter

Airflow vs pressure drop.

Phosgene gas life (performed by CRDL).

e Control Panel

Sand and dust, in accordance with MIL-STD-810.

Shock tests in accordance with Appendix B1.

Vibration in accordance with Appendix B1.

Humidity in accordance with Appendis B1.

Radio noise interference.

In addition to these tests, there will be additional proving tests to establish the compatibility of the E67 control panel with the E49 Filter Unit. These tests will include functional tests in the various operating modes of the Filter Unit.

C UNIT TESTS

Each of the tests performed on the Filter Unit will begin and end with a checkout consisting of a mechanical, electrical, and performance inspection. A change in the condition of the unit in any of the mentioned areas will be recorded in the test results.

1 Shock Tests

The shock tests will be conducted in the following manner. The shock waves will be recorded, using an accelerometer mounted on the base of the shock fixture. The output of the accelerometer will be recorded at each of 36 separate drops, through photographs of the oscilloscope screen. Prior to conducting tests, the accelerometer with the oscilloscope will be calibrated to read g's per centimeter from the "x" axis and milliseconds from the "y" axis. The magnitude and duration of shock will be as specified in Appendix B1. A series of six drops will be made on each of the six surfaces in the order of bottom, right side, left side, rear, front, and top. The test sequence will be performed twice to include both nonoperating and operating conditions.

2 Vibration

The vibration tests will be performed in accordance with Appendix B1. Input vibration will be controlled by an accelerometer affixed to the mounting flange of the Filter Unit. The output from this accelerometer will be recorded by an "xy" plotter, with acceler-

ation plotted in the "x" direction and frequency in the "y" direction. The acceleration plot will be in decimals. Input acceleration for nonoperating vertical vibration will be at 2.5 g's.

3 Radio Frequency Interference Tests

A radio frequency spectrum of the Filter Unit will be run to determine if the unit meets the requirement of MIL-I-11748B[34], using standard Signal Corp test procedures. Tests will be conducted at the US Army Electronic Research and Development Laboratories, Milwaukee, Wisconsin.

4 Humidity Tests

The humidity test will be conducted for operating conditions only in accordance with Appendix B1.

5 Barometric Pressure Tests

The unit shall be operated in an atmosphere equivalent to 10,000 feet (20.48 in. mercury) for 120 minutes as prescribed in Appendix B1.

6 Dust Removal Efficiency Tests

The efficiency of the mechanical separator will be measured at primary airflow (the air entering the crew compartment) of 200 and 400 cfm. This test will be performed on a complete E49 Filter Unit without a gas filter as illustrated in Figure B1.

a Pretest Checkout

Prior to tests, the precleaner section will be examined to insure that it has been properly assembled. The particulate filter will be weighed to the nearest gram. The precleaner and particulate filter will be placed in an E49 Filter Unit housing.

b Operating Tests

A pressure drop test will be run, using the test setup illustrated in Figure B2.

The Filter Unit will be operated at 400 cfm. AC Coarse Test Dust will be fed to the inlet at a rate of 660 grams per hour with a modified AFI dust feeder. The modification will consist of increasing the feed rate to conform to these specifications. After a period of 24 hours, this portion of the test will be terminated.

The particulate filter will be removed and reweighed, and the increase in weight recorded. A pressure drop test will be run, and the test data will be compared to the pressure drop at the start of testing.

The particulate filter will be reinstalled in the E49 Filter Unit housing and the tests outlined in the previous paragraphs will be repeated with the exception that the pri-

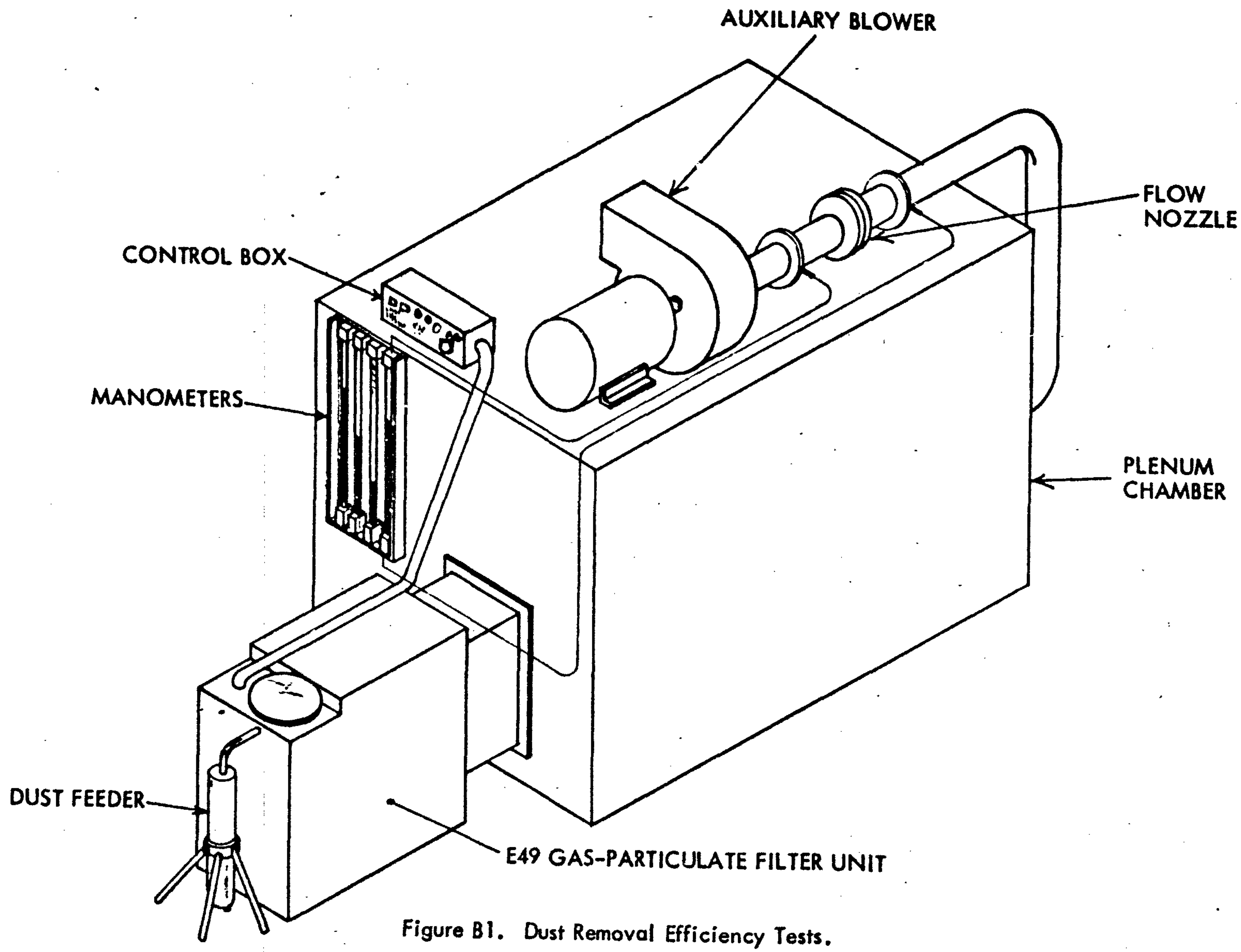

Figure B1. Dust Removal Efficiency Tests.

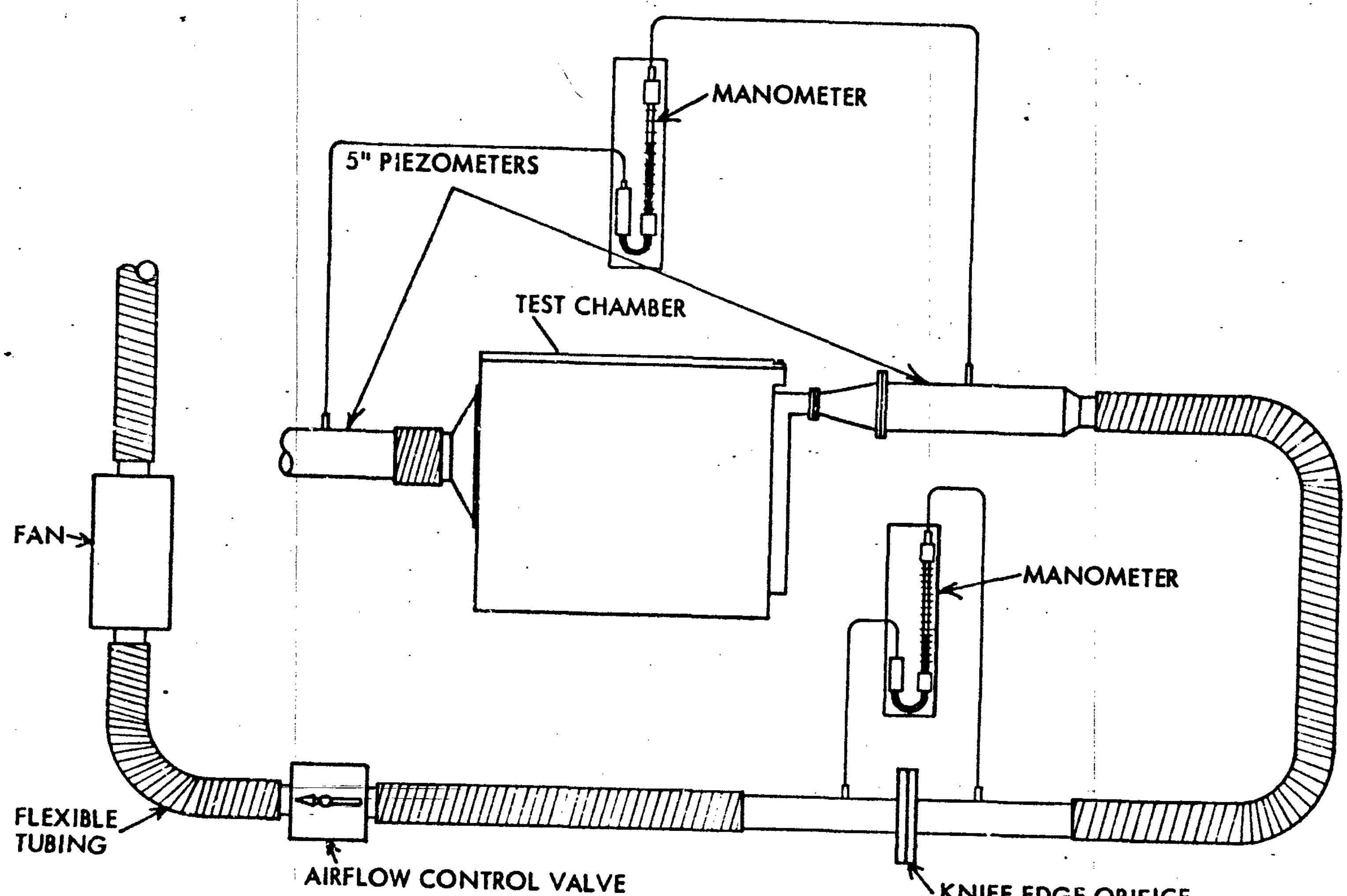

Figure B2. Pressure Drop Test.

mary airflow will be 200 cfm, the rate of dust feed will be 360 grams per hour, and the test will be run for 6 hours. At the end of this test, the particulate filter will be reweighed and the difference in weight recorded.

The efficiency of the mechanical separator will be determined by the formula; 1 minus the concentration of dust leaving the mechanical separator over the concentration of the dust entering the mechanical separator.

c Post-Test Checkout

At the completion of both tests, the precleaner will be removed and visually examined to insure that no leaks developed in the precleaner during the tests nor that any other malfunction occurred. Test data will be recorded on the forms included with this report.

7 Airflow Versus Pressure Drop Test

The pressure drop through the E49 Filter Unit at various air flows will be determined by using the test setup illustrated in Figure B1.

An auxiliary static pressure tap will be located in the blower housing, upstream from the tube section. The difference in pressure at this point and the pressure in the chamber will be measured and recorded. The tests will be run with the unit in the firing mode of operation which will place the flow control in the open position.

The pressure will be recorded at various points from the minimum to the maximum flow with a minimum of five recording points. The data will be presented in tabular form and plotted both on logarithmic and arithmetic paper.

D COMPONENT TESTS

A mechanical and electrical-operation inspection will be made of each component before and after each test.

1 Fan Assembly

The fan assembly must show the following minimal characteristics to meet the requirements of the E49 Filter Unit.

a Airflow Versus Pressure

The fan shall be tested as shown in Figure B3 with input voltage at $27.5^{+0}_{-.5}$ vdc. Pressure versus flow will be recorded in equal 50 cfm increments from the no flow, or point of shut off, to full flow.

b Radio Interference

A radio frequency spectrum of the motor will be determined using the stand-

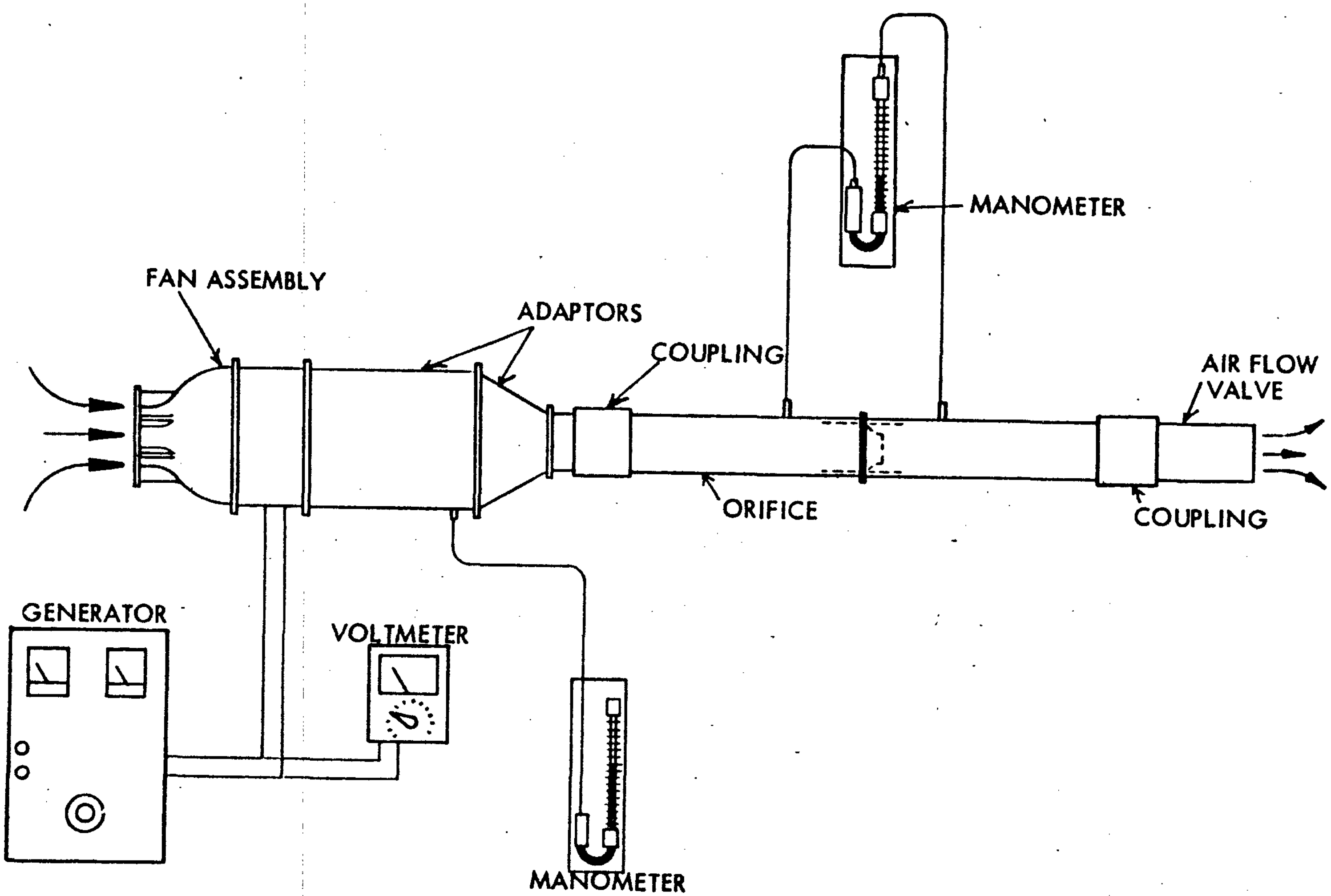

Figure B3. Airflow Versus Pressure Test.

ard Signal Corp procedures. Tests will be conducted at the US Army Electronics Research and Development Laboratories, Milwaukee, Wisconsin.

c Noise Level

Noise level of the fan will be measured in an anechoic chamber. The test equipment will consist of a condenser microphone with a flat frequency response to 18 kilocycles ±3 db, a sound vibration analyzer with a flat frequency response to 30 kc ±3 db, and related calibration equipment.

Readings will be taken at a 5-foot radius in a horizontal plane that passes through the geometric center of the fan. The readings will be taken both at the inlet and the exhaust portion of the fan. The 5-foot radius will be measured from the center of the impeller on the intake side and the center of the motor housing on the exhaust side. Readings will be taken in 30° increments through a 0 - 180° arc on the intake and exhaust sides.

Data will be recorded in nine octave bands measured in db. Data will be recorded overall in these octave bands, at the sound pressure level, in PNdb.

d Input Power

During the airflow versus pressure drop tests of the fan assembly, a record of voltage versus current will be made at each point. That is, from shut off to full flow in 50 cfm increments.

e Impeller Speed

The impeller speed will be recorded at each point of the test from shut off to full flow at 50 cfm increments during the airflow versus pressure drop test. This speed will be measured and recorded with a digital electronic counter, and recorded on a 10-second interval from that recorded at equivalent rpm.

f Endurance

The fan will be run continously at 440 cfm ±10 percent with a static pressure of 20 in. of water ± 10 percent for a period of not less than 250 hours, nor more than 1000 hours. Prior to running this test, the brushes in the fan motor will be measured and weighed. At the completion of the test, the brushes will again be measured and weighed and this data recorded.

This will be a continuous unattended test and will only be shut down if a failure of the fan or test setup occurs.

g Impeller Erosion

This test will determine the erosion resistance of the impeller in an environment of abrasive material. Silica flour, MIL-O-SIL or equivalent, will be fed at a rate of 0.1 grams per cubic feet for a period of not less than 44 hours. This test will be run in conjunction with the endurance test of the fans.

The pretest checkout of this unit will include an airflow versus static pressure curve of the fan. The fan impeller will be weighed to the nearest tenth of a gram. Any post-test checkout of this fan will include a flow versus pressure drop test in accordance with the procedures outlined in the airflow versus pressure test for this component. At the end of the test, the impeller will again be weighed on the same balance and its weight recorded to the nearest tenth of a gram. The impeller should be cleaned prior to weighing both in pretest and post-test.

h Vibration and Shock

The resistance of the fan assembly to vibration and shock will be determined during the vibration and shock tests of the E49 Filter Unit.

2 Dust Separator

The mechanical dust separator, without flow control, will be tested as shown in Figure B4. The pressure drop through the separator, with a constant scavenging flow of 40 cfm, will be recorded from 100 to 550 cfm in equal 50 cfm increments. The data will be presented as a tabulation of flow versus pressure drop.

3 Particulate Filter

a Airflow Versus Pressure Drop

The resistance of the particulate filter to airflow will be measured in equal 50 cfm increments between 100 to 400 cfm. The pressure drop will be recorded to the nearest hundredth of an inch of water. The test setup is shown in Figure B2.

The test will be conducted as follows:

The pressure drop at the flows specified in the previous paragraph of the housing, without filter, will be recorded.

The pressure drop of the filter and housing at these flows will be measured and recorded.

Pressure drop through the filter will be calculated by subtracting the pressure drop through the test setup and filter.

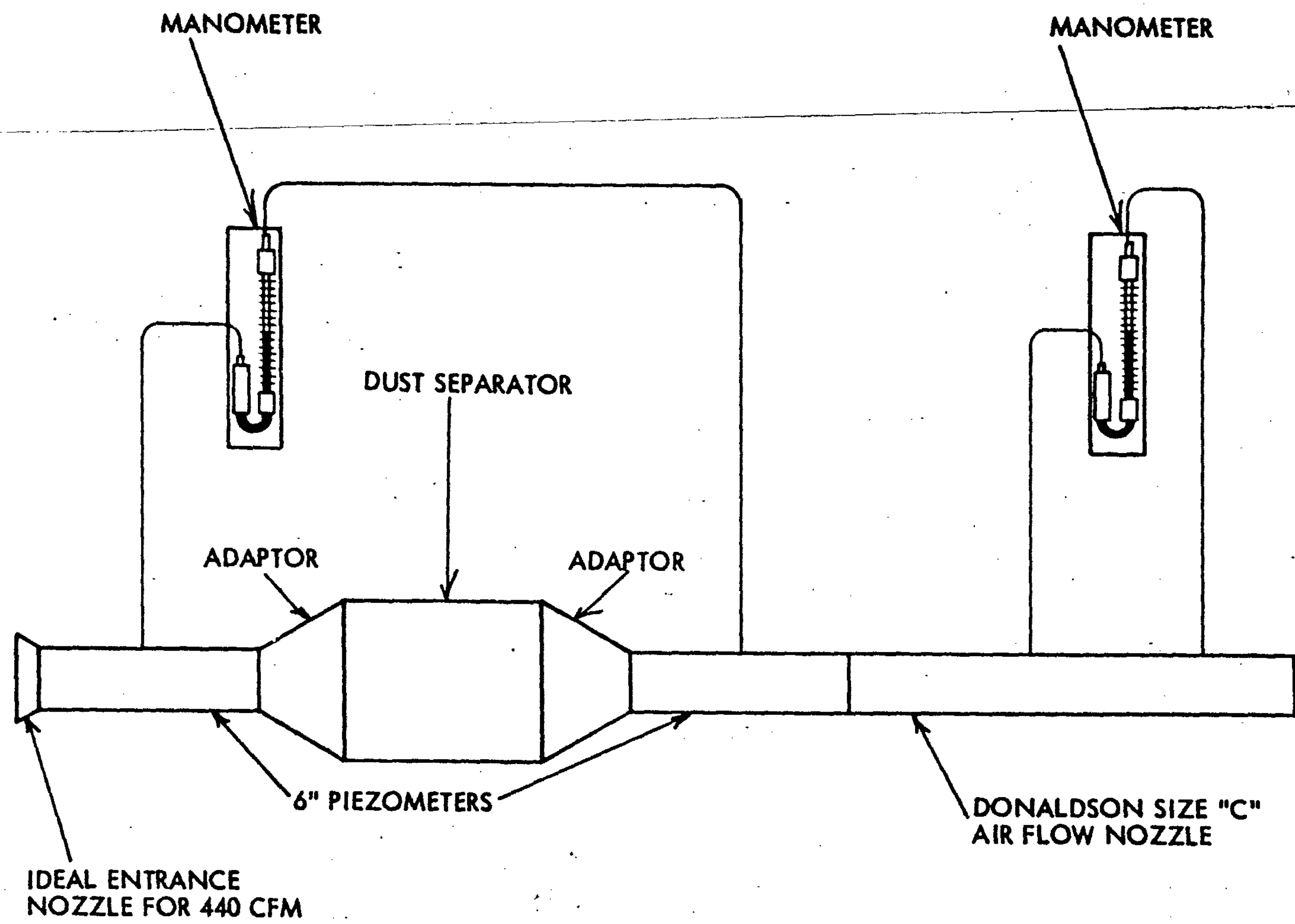

Figure B4. Airflow Versus Pressure Drop Test.

The pressure drop data will be presented in table form, showing the pressure drop through the filter and housing, the pressure drop through the test setup alone, and the difference between the two.

b DOP Penetration

The efficiency of the particulate filter will be determined using generated DOP smoke with the test setup shown in Figure B5. The penetration of the DOP smoke will be precalculated with NRL smoke penetration media. The penetration will be determined at 200 and 400 cfm.

4 Charcoal Gas Filter

a Airflow Versus Pressure Drop

The resistance of the gas filter to airflow will be measured in equal 50 cfm increments between 100 to 400 cfm. The pressure drop will be recorded to the nearest hundredth of an inch of water. The test setup is shown in Figure B4.

The test setup will be conducted as follows:

The pressure drop at the flows specified in the previous paragraph of the housing, without filter, will be recorded.

The pressure drop of the filter and housing at these flows will be measured and recorded.

Pressure drop through the filter will be calculated by subtracting the pressure drop through the test setup and filter.

The pressure drop data will be presented in table form, showing the pressure drop through the filter and housing, the pressure drop through the test setup alone, and the difference between the two.

b Phosgene Life

Phosgene life of the gas filter will be determined by Edgewood Arsenal, using standard test procedures, with data reporting on standard forms.

5 Control Panel

a Sand and Dust Test

The sand and dust test will be performed according to MIL-STD-810[30], Method 510, Procedure 1. The test will determine the resistance of the control panel to blowing fine sand and dust particles.

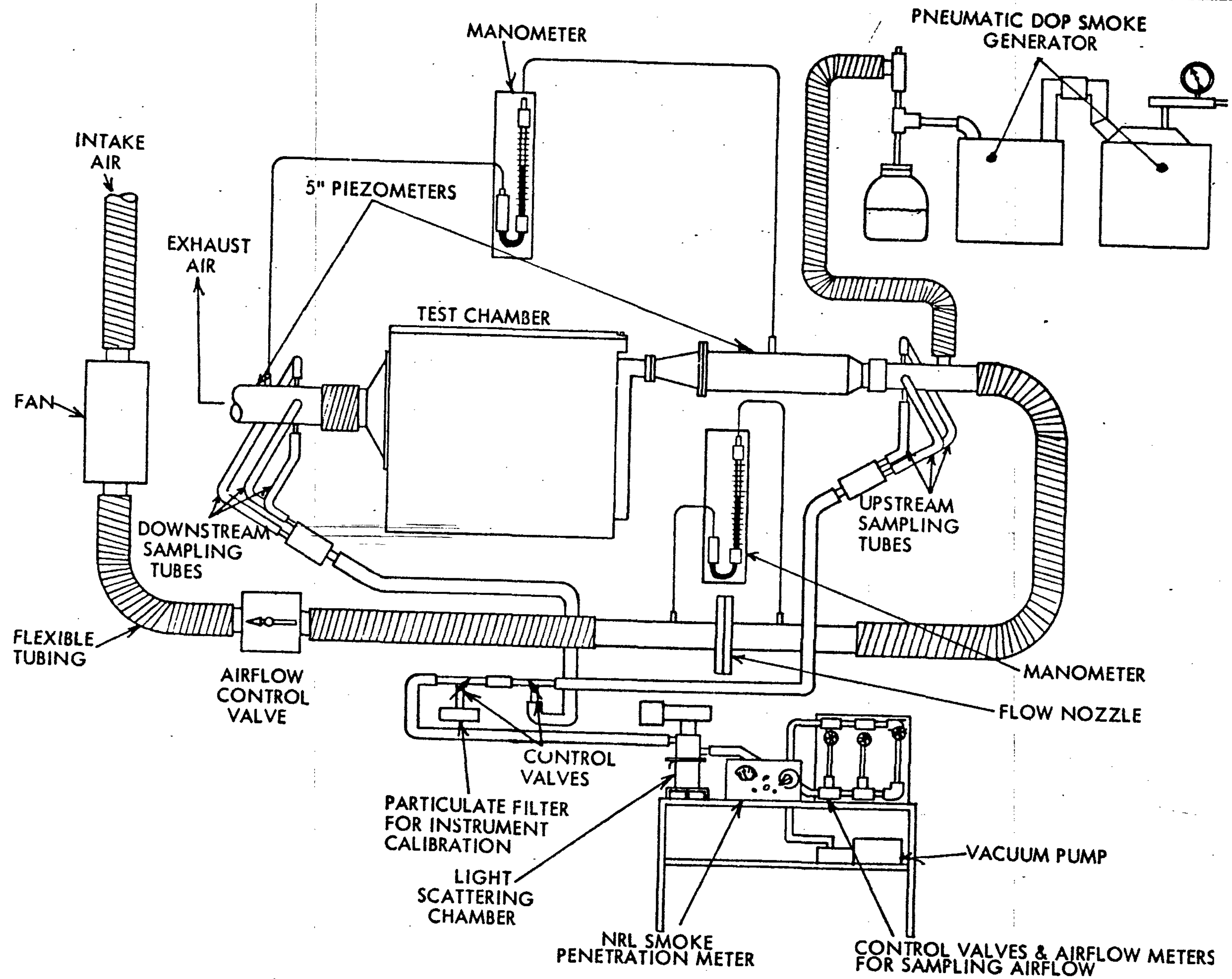

Figure B5. DOP Efficiency Tests.

The control panel will be placed in a test chamber. The sand and dust concentration will be maintained at 0.1 to 0.25 gram per cubic foot. The relative humidity shall not exceed 30 percent. The air velocity in the chamber shall be maintained at 100 to 500 feet per minute.

The test chamber temperature will be maintained at 77°F (25°C) for a period of two hours. The temperature will then be raised to 160°F (71°C) and maintained for a period of two hours. At the end of this period, the control panel will be removed from the test chamber and allowed to cool to room temperature. Accumulated dust shall be removed by brushing, wiping or shaking. The control panel will then be operated and the results compared with the pretest checkout.

b Shock Tests

The shock tests will be performed according to MIL-STD-810[30]. With the control panel nonoperating , Method 516, Procedure II will be used. With the control panel operating, Method 516, Procedure I will be used. The test consists of three shocks to each of the six sides of the panel, along the three mutually perpendicular axis (18 shocks). The shock wave form, duration, and magnitude will be recorded, using an accelerometer mounted on the shock test fixture, and photographs of the oscilloscope screen. Prior to the tests, the accelerometer and oscilloscope will be calibrated to read g's per centimeter from the "x" axis and milliseconds from the "y" axis. The magnitude and duration of the shock will be as specified in MIL-STD-810[30].

c Vibration Tests

The vibration tests will be performed for the operating condition specified in Appendix B1, using MIL-STD-810[30], Method 514, Table 514-1, under Equipment Class 5, Curve B; with the exception noted herein.

The control panel will be vibrated for four hours in each of three mutually perpendicular planes; per Figure 514-9.

Prior to vibration in each plane, the panel will be cold-soaked at -65°F for a period of eight hours.

For the first hour of vibration in each plane, the control panel will be held at a temperature of -65°F. After one hour, the panel will be removed from the cold chamber and will be allowed to return to room ambient temperature during the remaining three hours of vibration.

Input vibration will be controlled by an accelerometer mounted on the vibration test fixture. The output of the accelerometer will be recorded on an x-y plotter, with acceleration plotted in the x direction and frequency in the y direction.

An x-y plot of the vibration spectrum will be made during each test. There will be one vertical, transverse, and longitudinal plot for each of the low temperature and ambient temperature conditions.

d Humidity Test

The humidity test will be performed in accordance with Appendix B1.

The control panel will be subjected to 100 percent humidity at 125°F, while operating, for a period of two hours. Input voltage and amperage will be recorded for this period.

e Radio Frequency Interference Tests

The RFI test of the E67 control panel will be part of the RFI tests of the complete E49 Filter Unit, to be performed at the US Army Research and Development Laboratories, Milwaukee, Wisconsin. The tests will be conducted according to this development test plan.

APPENDIX C

RADIO FREQUENCY INTERFERENCE TESTS

E49 GAS-PARTICULATE FILTER UNIT

RETYPED COPY

HEADQUARTERS
UNITED STATES ARMY ELECTRONICS COMMAND
United States Army Electronics Laboratories
Fort Monmouth, New Jersey 07703

In Reply Refer To:
AMSEL-RD-FS

RETURN ADDRESS:
Acting Chief
USAELRDL Field Station No. 1
P.O. Box 6262
Milwaukee, Wisconsin

16 July 1965

SUBJECT: Contract DA-18-035-AMC-100(A) - Donaldson Company, Inc., Minneapolis, Minnesota

TO: Commanding Officer
U.S. Army Chemical R&D Laboratories
Attn: SMUEA-CR-DSPP (Mr. Gil Appel)
Edgewood Arsenal
Edgewood, Maryland 21010

1. Donaldson Company, Inc. submitted a development model Collective Protection Unit (E49 Filter Unit) to this Station to determine the effectiveness of the radio frequency interference reduction system being applied to the unit. Tests were performed in accordance with requirements of MIL-S-10379A on 14 and 15 April and 8 July 1965.

2. Conducted interference tests performed 14-15 April revealed that the interference from the following electrical sub-assemblies was in excess of the permissible limits of MIL-S-10379A:

a. Flow Control Motor
b. Hourmeter
c. Flasher Unit

Tests were not performed on the Fording Valve Motor. Since this unit will operate only for short periods during starting and stopping, suppression treatment will not be required.

3. Conducted interference tests were performed on each individual item to determine what additional interference reduction treatment or corrections would be needed to reduce the excessive interference to acceptable levels.

a. Tests on the Flow Control Motor showed that the feed-thru capacitors which were installed in each lead to the motor were defective and replacement with an approved compo-

AMSEL-RD-FS 16 July 1965

SUBJECT: Contract DA-18-035-AMC-100(A) - Donaldson Company, Inc., Minneapolis, Minnesota

nent resulted in satisfactory interference reduction. Since the interference reduction system for the Fan Motor also utilized feed-thru type capacitors, it was recommended that the contractor obtain certification that their capacitors will conform to MIL-C-11693 or obtain approved capacitors of other manufacturer.

b. Tests on the hourmeter and flasher unit showed they could be effectively suppressed by applying a capacitor across the terminals of the hourmeter and installing a feed-thru capacitor across the terminals of the hourmeter and installing a feed-thru type capacitor in series with the power to the flasher.

4. The contractor resubmitted his unit for further tests on 8 Jul 65. The unit incorporated the changes in the interference reduction system as previously recommended except that the Flasher was replaced with a flasher which is integrally shielded and suppressed. Radiated and conducted interference tests were performed to determine conformance to the requirements of MIL-S-10379A. Tests were also performed to determine the degree of effectiveness of the shielding applied to the power lead between the main fan motor and the feed-thru capacitor.

5. The tests showed that the radiated and conducted interference from the Collective Protection Unit (E49 Filter Unit) did not exceed the limits prescribed by MIL-S-10379A. The tests also showed that shielding of the power lead between the fan motor and feed-thru capacitor is not required for conformance to MIL-S-10379A. The description of the satisfactory interference reduction system for the fan motor, flow control motor, and hourmeter is described in Annex 302-23-1, five copies inclosed.

6. This Station is in the process of being inactivated and its function transferred to other organizations. Further inquiries regarding the radio frequency interference requirements on this and future contracts should be forwarded to the Commanding General, U.S. Army Electronics Command, Attention: AMSEL-RD-GF, Fort Monmouth, New Jersey 07703.

(Signature)

JOHN S. KASPROWSKI
Acting Chief

1 Incl
as

Copy furnished:
Donaldson Co., Inc.
Attn: Mr. Keith J. Conklin
1400 West 94th Street
Minneapolis, Minnesota 55431

CG, USAECOM
Attn: AMSEL-RD-GF
Ft Monmouth, NJ 07703

INTERFERENCE REDUCTION SYSTEM

AMSEL-RD-FS

Annex 302-23-1
16 July 1965

1. Item: Donaldson Company Collective Protection Unit (E49 Filter Unit)

2. Specification: MIL-S-10379A

3. Interference Reduction System:

a. Fan Motor - .3 HP, 28-volt DC, 112 ampere, 10,000 RPM:

A 10.0 uf, 100-volt DC, 115-ampere feed-thru capacitor inserted in series with the 28-volt DC positive lead to the motor. The capacitor is bonded to the precleaner assembly with plated tooth-type lockwashers.

b. Air Flow Control Motor - 28-volt DC;

A 1.0 uf, 200-volt DC, 10-ampere feed-thru capacitor inserted in each of two leads to the motor. The capacitors are bonded to their mounting surfaces with plated tooth-type lockwashers.

c. Hourmeter -

A 0.1 uf, 100-volt DC capacitor connected across the hourmeter input leads.

d. Flasher Unit -

The flasher unit is integrally shielded and suppressed by the manufacturer.

e. Fording Valve Motor - 28-volt DC:

Will operate only for short periods during starting and stopping, therefore, suppression treatment is not required.

Incl to ltr 16 Jul 65

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APPENDIX D

SUBSTANTIVE RELIABILITY FOR THE E49 GAS-PARTICULATE FILTER UNIT

A PURPOSE

This substantive reliability report is prepared for the following reasons:

To provide substantive reliability data in support of the assumptive reliability predictions given in Assumptive Predicted Reliability Report No. 1, dated 2 October 1964.

To report the results of the Reliability Demonstration Test of the E49 Filter Unit.

To report the results of Filter Unit component life tests.

B GROUND RULES

Reliability predictions stated in this report are based on:

A 90 percent confidence level.

An assumed 100 percent complete Maintenance Support for availability of personnel and material.

Manufacture in complete accordance with all drawings and specifications.

Only consideration of those failures causing loss or reduction of Filter Unit performance.

Dust life based on desert conditions where 100 percent concentration (zero visibility) is equal to 0.025 gm/cu ft of AC Coarse Test Dust and the vehicle usage makeup as stated in the Reliability Demonstration Test Plan.

Expected tracked vehicle operational life of 125,000 miles or 12,500 hours (10 miles equals one hour).

Filter Unit operation 100 percent of vehicle operation.

Deep-fording valve operational requirement of 81 cycles per 960 hours of Filter Unit operation.

Pressure sensing switch operational requirement of five cycles per each hour of Filter Unit operation.

C TEST EVALUATION

1 Environmental Tests

The E49 Filter Unit was subjected to, and passed, all contract required environmental testing.

The gas filter retaining mechanism buckled during nonoperating shock tests, but met the test requirements after minor redesign and retest.

The control panel was subjected to complete testing after updating to Class I status. One manufacturing deficiency was discovered in one of the switches of the control panel. This defect was corrected by the manufacturer and, under retest, the control panel passed all requirements without failure.

A complete test summary is contained in Section VI of this report. These results demonstrate that the Filter Unit meets the system requirements based on the ground rules listed in paragraph B of this appendix.

2 Component Reliability Tests

Component reliability tests were conducted on the E70 deep-fording valve and the pressure sensing switches of the pressure sensing control system. Based on the ground rules of this report, both tests demonstrated that the life of these components are in excess of system requirements.

The E70 deep-fording valve was cycled 50,000 times under static conditions without failure. This test can be derated 70 percent because of lack of the five environmental test requirements and still equal 15,000 cycles which is the equivalent of 177,778 hours of Filter Unit operation as compared with the 12,500 hour expected vehicle life.

The pressure switches were tested to 1,372,602 cycles under static conditions without failure. This test could be derated 70 percent because of the lack of applied environmental requirements and still equal 411,780 cycles which is equivalent to 82,356 hours of Filter Unit operation. This again exceeds the 12,500 hour expected vehicle life.

3 Reliability Demonstration Tests

A reliability demonstration test was performed on a Filter Unit previously used for development testing. The previous testing included a total of 105.5 hours as follows:

0.5 hours inspection running time.

2.2 hours barometric pressure tests.

2.4 hours humidity tests.

1.0 hours pressure drop tests.

99.4 hours dust test at a concentration of 0.025 gm/cu ft of AC Coarse Test Dust, equal to zero visibility.

The 105.5 hours developmental tests were included as part of the accumulated 1760 hours of the reliability demonstration test.

Reliability demonstration tests were performed in accordance with the Reliability Demonstration Test Plan included as paragraph D of this appendix. The test was run for 1760 hours without failure.

After 270 hours of operation, an electric hourmeter was incorporated in the test setup since the dc hourmeter of the control panel was recording 25 hours for each 24 hours of operation.

The variable airflow control damper malfunctioned during the fifth and sixth 48-hour cycle of test. The cam controlling the damper actuating mechanism was deficient. The cam lobes controlling the operation were not long enough and the coasting of the damper motor caused malfunctioning of the mechanism. This condition was corrected and no further problem occurred in this area.

The fan was inspected at 500 hours in accordance with maintenance requirements. Examination of brushes and the bearings revealed that the brushes were excessively worn and the bearings had brinelling occurring in the races. The fan assembly and motor manufacturers were contacted. A joint investigation of the fan motor was conducted by Donaldson Company, the fan manufacturer, and the fan motor manufacturer. It was determined that the commutator of the motor was eccentric to the motor shaft beyond the acceptable tolerance limits of the motor design. Also, the shaft end bearing of the motor to the shaft end bearing outer race retainer was excessively loose. The motors for the 12 preproduction models were also investigated. It was determined that the commutators of these motors were in the same condition due to a manufacturing method change. The situation was corrected for all fans manufactured under these conditions and will be maintained on all future production. Upon return of the fan, the reliability test was resumed.

The unit was then run for one thousand consecutive hours to an accumulative total of 1500 hours and was shut down and disassembled for the 1000 hour maintenance check. Upon examination of the brushes in the motor it was determined that the brush wear was negligible after 1000 hours and the bearing movement was very smooth. The unit was then reassembled without any replacement of parts and the reliability test resumed.

The final 260 hours of test was completed without failure.

During the course of reliability tests, five switch indicator lamps burned out. Three of these were the NOT MAX FLOW switch indicator lamps and two were the UNIT ON/ DO NOT FORD switch indicator lamps. The most probable cause of this burn out was the alarm horn. The horn operated 2-1/2 minutes out of every 90 minutes or a total of 80 minutes per 48 hour cycle throughout continuous reliability test. Therefore, it has been judged that the malfunction was caused by the extended vibration from the horn and the close location of the switches to the horn. This is not considered a failure since this condition would not exist during normal operation. The alarm horn was allowed to operate under these conditions only for the convenience of the reliability test. However, it did demonstrate a high reliability for the alarm horn.

The results of this test, with the developmental engineering environmental tests and the reliability component life tests, substantiates the predicted 880 hour minimum MTBF as stated in the Assumptive Reliability Study.

D RELIABILITY DEMONSTRATION TEST PLAN

1 Introduction

This Reliability Demonstration Test Plan is used in substantiating those assumptive reliability predictions as reported in the Assumptive Predicted Reliability Report No. 1, dated 2 October 1964.

2 Ground Rules

This test is used only to substantiate the electrical parts and components assumed predicted reliability.

The test does not subject the unit/s to the following environments:

- Shock
- Vibration
- Humidity
- Barometric Pressure
- Radio Frequency Interference
- Dus:

Data from Development Testing forms the basis for evaluating the units from the following Reliability Factors:

a. Mechanical - ability of unit to withstand maximum pressures, stresses, and load combinations.

b. Functional - fail-safe features, interchangeability, etc.

c. Performance - conforming to the statement of work of Contract DA-18-035-AMC-100(A).

Rated Airflow

The unit will be operated to produce approximately 400 cfm of air at a minimum 1-inch (water gage) pressure at the unit outlet. For this demonstration the approximate 400 cfm will be the mean flow. The airflow will be varied once every 1.5 hours from the mean flow to maximum flow, to minimum flow, and returned to mean flow. The purpose of this requirement is to cycle the flow control components. Approximate airflow will be measured by monitoring the pressure output of the fan assembly manually using a manometer.

3 Military Characteristics - Use Conditions

The use conditions for the test operation, and establishing the predicted MTBF curves, and the Reliability Predictions of the Filter Unit are specified below.

a. Assumed Use Conditions

Mission Duration (MD) equals 48 hours.

Dust Concentration (DC) based on the Vehicle Usage make-up as specified below.

Zero visibility equals 0.025 gm/cu ft AC Coarse Test Dust

Vehicle Usage Make Up	MD, percent	Hours	DC, percent of zero visibility
Idle Time	40	19.2	1
Cross Country	40	19.2	70
Secondary Roads	20	9.6	35

The dust concentration specified above will be used to predict the probable erosion life of parts subject to erosion and also the probable dust life of the particulate filter.

b. Contract Specified Use Conditions

Power Source - the unit/s will be powered by a constant power source capable of supplying 27.5 ± 0.5 volts dc.

Output Pressure - unit/s must maintain a minimum pressure of 1-inch (water gage) pressure measured at the outlet of the unit.

c. Maintenance

Maintenance will be performed on the fan only:

1. Because of the 99.4 hours of dust test, the fan will be checked at 500 hours to determine the condition of the motor brushes and bearings.
2. If at 500 hours the brushes and bearings are replaced, the fan will not be checked until a total of 1500 hours or 1000 hour maintenance interval has been reached.
3. Maintenance will be performed at this time only if inspection of the fan assembly deems it necessary.

d. General Test Procedures

1 Test Unit/s Pretest Inspection

Inspect unit, to be tested, complete from both mechanical and electrical aspects. Correct any deficiencies caused by Development Tests. Restore the unit to a status equal to the condition prior to Development Test, to the maximum degree possible. Record all data on areas of the unit that were not, or could not be, restored.

2 Test Set-up

Unit will be set up with adapters and equipment necessary to operate, measure and control unit as specified below (See Figure D1):

Continuous duty power source capable of maintaining 27.5 ± 0.5 vdc with a safety device to protect the unit/s and the power source when test is run.

Set up duct work downstream of unit. The duct work will incorporate a damper to maintain the mean flow. The damper will also vary the flow. The damper will be cycled automaticully by use of an electric timer controlled actuator.

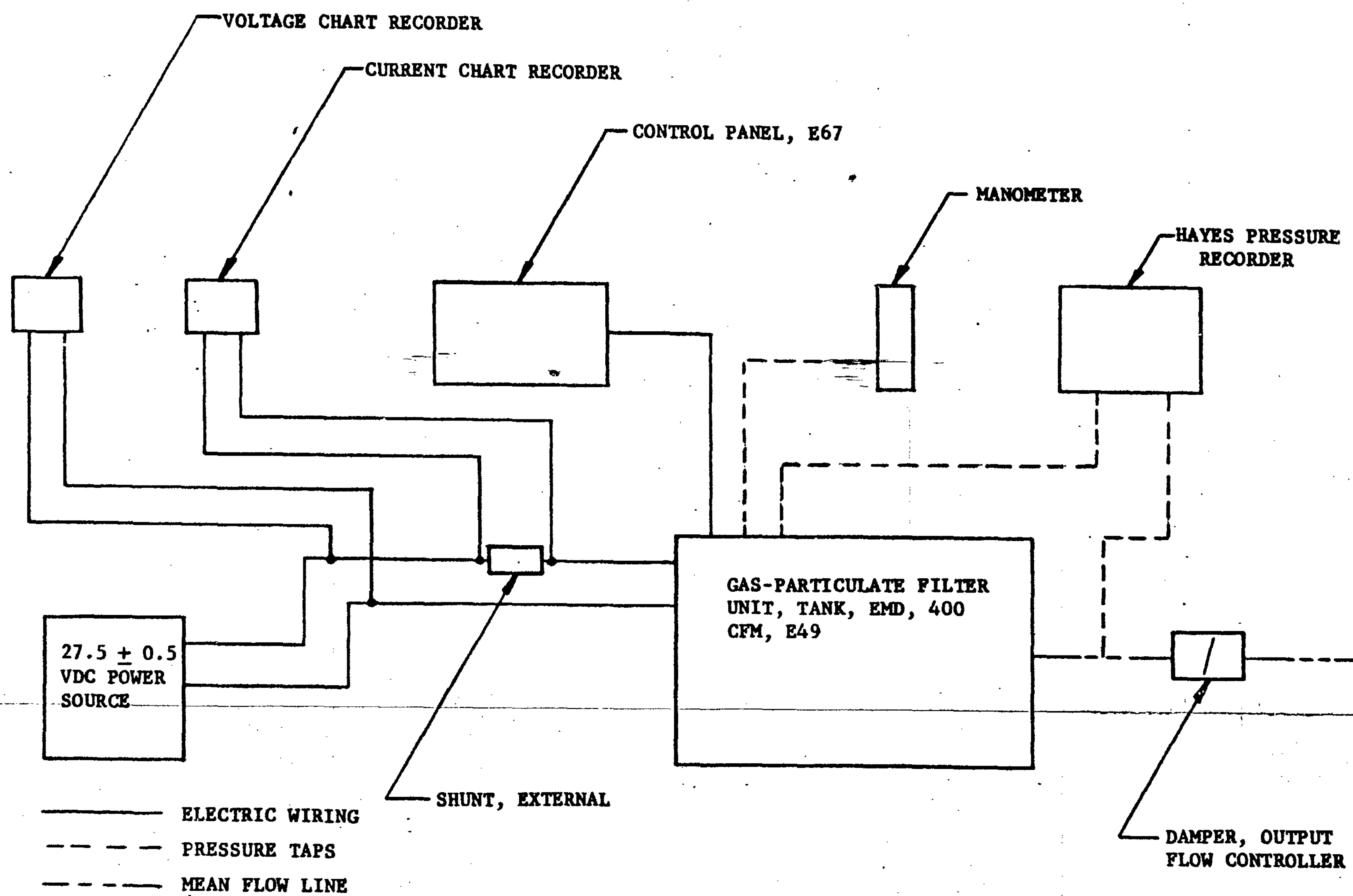

Figure D1. Reliability Demonstration Test Set-Up.

Equipment Required

Pressure recorder. The Contract Project Officer has given Donaldson Company verbal approval to use an existing Hayes Pressure recorder from Edgewood Arsenal. He will make it available for the Reliability Demonstration Test.

Voltage recorder

Amperes recorder

Damper (flow control)

Timer for damper cycling

Damper actuator

Power Source

Sensor, fan assembly output pressure (Manometer)

3 Data Recording

Use data log cards to record analyzed data.

Characteristic	Method
Voltage	Recorder
Amps	Recorder
Time elapsed	Hourmeter of unit/s Control Panel
Pressure	Recorder
Failures	Manually and recorder
Time of failure	Manually and recorder
Flow	Manually
Failure analysis	Manually

4 Pre-Test Set-Up Checkout

Switch on power supply.

Place control panel power switch in on position.

Push fan-on switch to start systems.

Check varied airflow controller.

Check recording equipment.

Adjust setup to establish 1-inch water pressure and mean flow.

5 Operational Sequence

Record start time.

Start unit.

Operate unit for a minimum duration of 48 hours on a 1.5 hour cycling basis to a total of 36 cycles per the 48 hours. At each 1.5 hour interval the airflow will be varied as specified in the Ground Rules of the test plan.

At the end of the 48 hour duration, the unit will be shut down. Unit will remain shut down for two hours minimum to simulate vehicle turn around time.

Repeat these operations until the assumed predicted minimum MTBF of 880 hours based on the predicted average MTBF of 2341 hours has been demonstrated by a test duration of 1760 hours without failure or by a test duration of 4682 hours or two failures, whichever is the longest test duration. A test duration of 1760 hours without failure would demonstrate the 880 hour minimum MTBF. The test duration of 4682 hours or two failures, whichever is greater, would demonstrate both the minimum MTBF of 880 hours and the predicted average MTBF of 2341 hours. The expected upper limit of testing to two failures is 8750 hours. The above predictions are based on a 90 percent confidence level.

6 Failure Definition

Manufactured defects will not be considered as failures.

Lack of required maintenance by cause will not be considered as failures.

Catastrophic failure - a sudden change in the operating characteristics of the unit resulting in complete loss of purified or pressurized air.

Failure - dependent (secondary) caused by malfunctioning of associated items. Not independent.

Flow control failure would cause reduced life if failure occurs in maximum oper. position. In closed position would cause lack of flow for firing mode.

Failure of fan assembly thermal overload would cause complete burn out of fan assembly.

Failure - independent (primary) occurs without being related to the malfunctioning of associated items. Not dependent.

Bearing failure in fan assembly would cause complete loss of airflow.

E RELIABILITY PREDICTIONS

1 Dust Life

Based on the dust life of the ground rules for this reliability report, the following predictions are made:

<u>E49 Gas-Particulate Filter Unit</u>

The unit will be capable of delivering 430 cfm of air at 1-inch (water gage) pressure measured at the unit outlet after a 48-hour mission.

<u>E59 400 cfm Particulate Filter</u>

With the particulate filter in normal use (predicted vehicle usage), the E49 Filter Unit shall have a predicted dust life of 70.0 hours or the equivalent of approximately 1.5 48-hour missions.

2 Substantive Predicted Reliability

Based on the test data from the developmental engineering, component reliability, and reliability demonstration test, engineering analysis after redesign of the control panel and component panel of the precleaner, the following reliability predictions are made:

> Using the exponential theory of reliability and reliability equations as given in Section 2-2 of the Assumptive Reliability Study, dated 2 October 1964, the predicted reliability for 1000 hours operation is equal to 57.72 percent. The predicted average MTBF of a unit will be 2365 hours. The predicted minimum MTBF at 90 percent confidence limit, based on 2365 hour average MTBF, will be 889 hours. These reliability predictions reflect an increase over the assumed reliability of 880 hours (reference paragraph C5).

F PREDICTED RELIABILITY FAILURE RATE DATA

Predicted reliability failure rate data in the following tables show only the failure rate data concerning failures that will cause the reduction or loss of required unit performance. In comparing Table D1 of the failure rate data with the assumptive reliability failure rate data, it will be noticed that item number 5 failure rate and item number 8 failure rate has decreased. Item number 11 failure rate has been increased.

1 Failure Rate Data Changes

Gas Filter

The gas filter failure rate has been decreased to equal the horizontal gas filter design. This has been accomplished through redesign of this vertical gas filter by the use of a rubber pressure pad on the top of the vertical gas filter and an increase in the charcoal reservoir at the top of the air chambers. The result of this redesign is an extended life under vibration and shock. Through engineering analysis it has resulted in a decrease of 2.000 in the failure rate on the gas filter retaining mechanism. The retaining mechanism was redesigned for self-locating of filters, added strength and resistance to shock and vibration for the gas filter as well as the particulate filter. Through engineering analysis it has resulted in a 50 percent or 0.400 decrease in failure rate.

Control Panel

The control panel failure rate, Item 11, has increased from 3.662 to 4.602. This is the result of complete redesign and miniaturization of the control panel. The redesign resulted in adding of components into the control panel, based on MIL-HDBK-217, which has caused the increase. The engineering analysis used for this failure rate data was based on all engineering and reliability testing and n engineering mathematical analysis of redesign.

TABLE D1. PREDICTED RELIABILITY FAILURE RATE DATA AFFECTING UNIT PERFORMANCE *

MTBF = Mean Time Between Failure, hr λ = Failure Rate at $1/MTBF/10^3$ hr

Comp. No.	Component Name	Component Rating MTBF	Component System (%) λ	Basis
1	Seal Device	1,100,000	0.091	From the totaled values on subtable.
2	Motor-blower	11,250	8.870	From the totaled values on subtable.
3	Dust Separator	1,000,000	0.100	Result of engineering analysis.
4	Particulate Filter	20,000	5.000	Result of engineering analysis.
5	Gas Filter (GF) Vertical	16,666	6.000	Result of engineering analysis.
6	CPU Housing	500,000	0.200	Result of engineering analysis.
7	Retaining Mechanism	250,000	0.400	Result of engineering analysis.
8	Dust Exhaust	500,000	0.200	Result of engineering analysis.
9	Flow Control	6,050	16.524	From the totaled values on subtable.
10	Control Panel	27,350	4.602	From the totaled values on subtable.
11	Wire and Interconnectors	339,000	0.295	From the totaled values on subtable.
	TOTAL	2365	42.282	

* Concerning only failures that will cause the reduction or loss of required unit performance.

TABLE D2. INLET SEAL DEVICE*

Comp. No.	Component Name	Component		Basis
		Rating No. Req'd	System (%) λ	
1	Limit Switch (S8, 9, & 10)	3	0.020	From MIL-HDBK-217 assume Type V.
2	Connector	1	0.008	From MIL-HDBK-217 based on 8 active pins.
3	Connector	1	0.008	See item 2.
4	Motor (dc)	1	0.015	From MIL-HDBK-217 based on 12,000 rpm brush motor, 70°C - B insulation 81 cyc/960 hr use.
	TOTAL		0.091	

* See Note.

TABLE D3. FAN

Comp. No.	Component Name	Component		Basis
		Rating No. Req'd	System (%) λ	
1	Blower Motor Overload (S15)	1	0.100	From MIL-HDBK-217 low population parts circuit breaker (thermal).
2	Motor (dc - 3 hp)	1	8.750	From MIL-HDBK-217 on 10,000 rpm brush motor plus heat correction B-insulation.
3	Power Relay	1	0.020	From MIL-HDBK-217 assume Type N.
	TOTAL		8.870	

TABLE D4. FLOW CONTROL*

Comp. No.	Component Name	Component Rating No. Req'd	Component System (%) λ	Basis
1	Limit Switch (S6 & 7)	2	0.020	From MIL-HDBK-217 assume Type V.
2	Low Pressure Relay	1	0.270	From MIL-HDBK-217 assume Type C plus amp correction.
3	Relay Socket	1	0.008	From MIL-HDBK-217 connector based on 9 active pins.
4	Connector	1	0.008	From MIL-HDBK-217 based on 8 active pins.
5	Connector	1	0.008	See item 4.
6	Motor (dc)	1	16.175	From MIL-HDBK-217 based on 14,000 rpm brush motor, 70° -B insulation, general purpose class.
7	Connector	3	0.005	From MIL-HDBK-217 based on 3 active pins.
	TOTAL		16.524	

* See Note.

TABLE D5. CONTROL PANEL*

Comp. No.	Component Name	Component Rating No. Req'd	System (%) λ	Basis
1	Switch S1	6	0.180	From MIL-HDBK-217 assume Type X plus amp correction.
2	Switch S11	1	0.180	See Switch S1.
3	Switch S5	4	0.180	See Switch S1.
4	Switch S13	10	0.180	See Switch S1.
5	Switch S12	1	0.280	From MIL-HDBK-217 assume Type X plus amp and pole correction.
6	Connector	1	0.022	From MIL-HDBK-217 based on 28 active pins.
7	Circuit Breaker	4	0.100	From MIL-HDBK-217 low population parts circuit breaker (thermal).
8	Dimmer Sw'tch (R1, 2, & 3)	3	0.040	From MIL-HDBK-217 assume Type Z plus pole correction.
	TOTAL		4.602	

* See Note.

TABLE D6. WIRE AND INTERCONNECTORS*

Comp. No.	Component Name	Component		Basis
		Rating No. Req'd	System (%) λ	
1	Connector	1	0.022	From MIL-HDBK-217 basis 28 active pins.
2	Connector	1	0.023	See item 1, 29 active pins.
3	Connector	1	0.023	See item 1, 29 active pins.
4	No. 20 Wire		0.220	From MIL-HDBK-217 approximately 300 connections.
5	No. 4 Wire		0.007	From MIL-HDBK-217 approximately 10 connections.
	TOTAL		0.295	

* See Note.

APPENDIX E

COORDINATION MEETINGS - CONTRACT DA-18-035-AMC-100(A)

DATES	LOCATION	ATTENDEES	PURPOSE
1,2,3 Oct 63	Edgewood Arsenal	Donaldson Personnel T.A. Baden K.J. Conklin E.E. Grassel	Contract Orientation and literature search.
17-18 Oct 63	ATAC	Donaldson Personnel T.A. Baden K.J. Conklin D.J. Dudrey	Integrate Filter Unit to MBT.
30-31 Oct 63	Chillicothe, Missouri Plant of Donaldson Company, Inc.	Donaldson Personnel D.O. Sata	Specialized pleating of filter media for dust filter.
18-19 Nov 63	Donaldson Co., Inc.	Edgewood Arsenal Personnel W. Lieske	Review Donaldson Frecn & DOP test equipment.
3-4 Dec 63	Donaldson Co., Inc.	Edgewood Arsenal Personnel F. Ort W. Linkous	Review contract progress.
14,15,16 Jan 64	Edgewood Arsenal	Donaldson Personnel T.A. Baden K.J. Conklin E.E. Grassel D.O. Sata	Review of Design Study Report and approval of Reliability Program.
30-31 Jan 64	Donaldson Co., Inc.	Edgewood Personnel G. Appel ATAC Personnel M. DuBay	Review and approve Design Study Report.
26-27 Feb 64	ATAC	Donaldson Personnel T.A. Baden K.J. Conklin E.E. Grassel	Review Design Study Report and select most promising designs.
12 Mar 64	Donaldson Co., Inc.	Edgewood Personnel H.O. Huss	Review Value Analysis Program.

DATES	LOCATION	ATTENDEES	PURPOSE
24-25 Mar 64	Donaldson Co., Inc.	<u>Edgewood Personnel</u> F. Ort W. Linkous	Contract progress review.
1 Apr 64	Donaldson Co., Inc.	<u>Gov't Personnel</u> Col. R.J. MacDon-ald, OCRD I. Cort - Army Material Command A. O'Konski - Army Material Command A. Cooke - Edgewood L. Jonas - Edgewood	Review contract and status report.
16-17 Apr 64	Edgewood Arsenal	<u>Donaldson Personnel</u> R.J. Lunn T.A. Baden	Review contract progress.
8 May 64	Donaldson Co., Inc.	<u>Gov't Personnel</u> F. Ort - Edgewood Lt. Short - Muni-tions Command	Review contract status and breadboard units.
25-26 May 64	Donaldson Co., Inc.	<u>Edgewood Personnel</u> G. Appel W. Linkous D. Moore <u>ATAC Personnel</u> M. DuBay C. Lorentzen	Review test results on breadboard units and review coordination drawings.
27 May 64	Donaldson Co., Inc.	<u>Edgewood Personnel</u> E. Engquist	Contract briefing and status report.
24-25 Jun 64	ATAC	<u>Donaldson Personnel</u> T.A. Baden K.J. Conklin D.W. Schoen	Approve coordination drawings of promising filter units.
30 Jun 64	Donaldson Co., Inc.	<u>Edgewood Personnel</u> B. Witherspoon	Review of Reliability Program.
15-16 Jul 64	Donaldson Co., Inc.	<u>Edgewood Personnel</u> C.G. Hain J. Maxa W. Linkous L. Valcarenghi	Review of drawings, Quality Assurance, and Specifications.

DATES	LOCATION	ATTENDEES	PURPOSE
6 Aug 64	Donaldson Co., Inc.	Edgewood Personnel A. West	Contract briefing and status report.
12,13,14 Aug 64	Donaldson Co., Inc.	Edgewood Personnel G. Appel D. Moore W. Linkous ATAC Personnel M. DuBay	Review filter unit working models and contract progress review.
16 Sep 64	Donaldson Co., Inc.	Edgewood Personnel J.W. Lewis	Review of Human Factors program.
16,17,18 Sep 64	Donaldson Co., Inc.	Edgewood Personnel J. Maxa	Review Class II drawings of optimum filter unit.
24-25 Sep 64	Edgewood Arsenal	Donaldson Personnel T.A. Baden K.J. Conklin	Review Edgewood demonstration setup control panel design.
6,7,8 Oct 64	Donaldson Co., Inc.	Gov't Personnel G. Appel-CRDL C. Lorentzen-ATAC	Review contract design effort and coordination.
29-30 Oct 64	Edgewood Arsenal	Donaldson Personnel T.A. Baden R.J. Lunn	Review contract progress.
3,4,5 Nov 64	Edgewood Arsenal	Donaldson Personnel N. Stenoien	Review rough draft of POMMs.
13 Nov 64	Edgewood Arsenal	Donaldson Personnel K.J. Conklin	Troubleshoot problems on working model.
17,18 Nov 64	Donaldson Co., Inc.	Edgewood Personnel W. Linkous J. Maxa D. Moore	Finalize Class II drawings and POMMs for Phase I.
18,19,20 Nov 64	Donaldson Co., Inc.	Edgewood Personnel J. Boardway	Review Donaldson Freon test equipment and procedures.

DATES	LOCATION	ATTENDEES	PURPOSE
19,20 Nov 64	Donaldson Co., Inc.	Gov't Personnel F. Ort - CRDL R. Sherfy - ERDL M. DuBay - ATAC C. Lorentzen-ATAC Harrison Rad. Div. Personnel M.W. Baker A. Tocco	Coordinate Filter Unit, E49 to ECU and both to MBT.
30 Nov 64 1 Dec 64	ATAC	Donaldson Personnel T.A. Baden	Review installation of E49 Filter Unit into test vehicle.
2,3 Dec 64	Donaldson Co., Inc.	Edgewood Personnel G. Appel	Review contract progress and documentation.
10 Dec 64	Pacific Car & Foundry	Donaldson Personnel K.J. Conklin	Review installation of E49 Filter Unit into test vehicle.
6,7,8 Jan 65	Donaldson Co., Inc.	Edgewood Personnel G. Appel	Review contract progress.
27,28 Jan 65	Edgewood Arsenal	Donaldson Personnel T.A. Baden K.J. Conklin J.H. Scott	Review contract progress.
28 Jan 65	Aberdeen Proving Ground	Donaldson Personnel J.H. Scott	Familiarization with shock tube test apparatus.
10,11,12 Feb 65	Donaldson Co., Inc.	Gov't Personnel G. Appel-CRDL W. Linkous-CRDL C. Hain-CRDL L. Valcarenghi-CRDL E. Boyce-CRDL D. Moore-CRDL C. Lorentzen-ATAC Mr. Groleau-Chi. Proc. Dist. P. Krueger-Chi. Proc. Dist.	Review Purchase Descriptions, Inspection Aids, Quality Assurance.

DATES	LOCATION	ATTENDEES	PURPOSE
8-12 Mar 65	Aberdeen Proving Ground	Aberdeen Personnel G. Coulter Edgewood Personnel G. Appel F. Ort H. Thorson W. Spindler J. Stalling Donaldson Personnel J. Scott J. Silvernail	Perform blast hazard tests.
24,25 Mar 65	Edgewood Arsenal	Gov't Personnel C. Lorentzen-ATAC S. Grabowski-ATAC G. Harley-APG G. Appel-CRDL F. Ort-CRDL C. Houff-CRDL Donaldson Personnel T.A. Baden K.J. Conklin D.O. Sata	Review purchase descriptions, reliability demonstration, Quality Assurance, and Human Factors on control panel.
26 Mar 65	Aberdeen Proving Ground	Gov't Personnel W. Linkous-CRDL Donaldson Personnel K.J. Conklin	Discuss correlation of laboratory vs field vibration test.
14 Apr 65	Edgewood Arsenal	Donaldson Personnel T.A. Baden	Review contract progress.
14,15 Apr 65	U.S. Army Electronics R&D Lab, Milwaukee, Wisconsin	Donaldson Personnel K.J. Conklin	Radio frequency interference tests.
27,28 Apr 65	Donaldson Co., Inc.	Gov't Personnel Lt. W. Gooley, Dugway	Observe dust capacity and efficiency test on E49.
19,20,21 May 65	Donaldson Co., Inc.	Gov't Personnel G. Appel	Coordinate control panel design, analyze reliability program.

DATES	LOCATION	ATTENDEES	PURPOSE
26,27,28 May 65	Edgewood Arsenal	Donaldson Personnel K.J. Conklin N.E. Stenoien O.H. Voxland	Review purchase descriptions, manuals and training program.
8-9 Jul 65	U.S. Army Electronics R&D Lab, Milwaukee, Wisconsin	Donaldson Personnel K. Anderson K. Conklin	Radio frequency interference tests.
19-23 Jul 65	Donaldson Co., Inc.	Gov't Personnel G. Appel C. Hain J. Moyer	Review and coordinate Quality Assurance Program.
3-5 Aug 65	Edgewood Arsenal	Donaldson Personnel D.O. Sata	Review packaging and purchase description status.
7-10 Sep 65	Donaldson Co., Inc.	Edgewood Personnel V. Johnson	Review training aids and lesson plans.
27-30 Sep 65	Donaldson Co., Inc.	Edgewood Personnel G. Appel T. Cornick W. Linkous J. Maxa	Sign off Class I drawings.

APPENDIX F
GLOSSARY OF TERMS

C_o	Challenging Gas Concentration, standard of 5.4 mg/liter
H	Length of Operation at Dust Concentration of 0.025 gm/cu ft, hr
N_{ra}	Filter Restriction Use
H_s	Length of Operation at Dust Concentration Other Than 0.025 gm/cu ft, hr
I	Electrical Current, amp
K	Conversion Factor
N_o	Saturation Capacity, gm of gas/gm of charcoal at 125°F
Q	Airflow, cfm
Q_n	Primary Air Flow Per Dust Separator Tube, cfm/tube
Q_p	Primary Air Flow, cfm
Q_s	Scavenging Air Flow, cfm
Q_t	Total Air Flow, cfm
V_o	Velocity Through Gas Filter Bed, standard of 19.2 cm/sec
W_f	Dust to the Particulate Filter, gm
β	Gas Life at 10 mg/liter Phosgene, min
γ	Fractional Penetration of Dust Through the Dust Separator
ΔP	Pressure Drop, inches of water
ΔP_c	Pressure Drop Due to Configuration Losses and Pressure in Crew Compartment, in. water
ΔP_f	Output Pressure of Fan Assembly, in. water
ΔP_g	Pressure Drop Through Gas Filter, in. water
ΔP_p	Pressure Drop Through Clean Particulate Filter, in. water
ΔP_t	Pressure Drop Through Dust Separator, in. water

λ	Total Charcoal Bed Depth, in.
λ_c	Critical Charcoal Bed Depth, in.
μ	Micron

APPENDIX G
REPORT REFERENCES

The following source documents are referenced in this report:

1. "Filter Medium, Fire-Resistant, High-Efficiency", MIL-F-51079, 6 April 1962.
2. "Filter, Particulate, High-Efficiency, Fire-Resistant", MIL-F-51068, 31 August 1962.
3. "Charcoal, Activated, Impregnated, ASC", MIL-C-13724A, 4 May 1960.
4. "Design and Development of a Collective Protection System for the Main Battle Tank, Design Study Report", Contract DA-18-035-AMC-100(A), Donaldson Company, Inc., January 1964.
5. "Filter Units, Protective Clothing, Gas-Mask Components and Related Products, Performance-Test Methods", MIL-STD-282, 28 May 1956.
6. "Adhesive, Sealing, for Filters", MIL-A-3562B, 2 January 1959.
7. "Edgeseal Material", MIL-E-51065, 30 August 1961.
8. Kloty, Irving M., "The Adsorption Wave", Handbood on Aerosols, US Atomic Energy Commission, 1950, p 8.
9. Guyton, H.G. and Lense, F.T., "Methods for Evaluating Respiratory Protection Masks and Their Component Parts", paper included in "Report on Symposium on Respiratory Protective Devices and Civil Defense", 4 April 1955, PB 121 162.
10. "Design and Development of a Gas-Particulate Filter Unit for the Main Battle Tank, Feasibility Study Report", Contract DA-18-035-AMC-100(A), Donaldson Company, Inc., December 1964.
11. Hedgcock, R.E. and Chaillet, R.F., "Human Factors Engineering Design Standard for Vehicle Fighting Compartments", HEL Standard S-2-64, May 1964.
12. "Process and Performance Requirements for Hard Coating Treatment of Aluminum Alloys", AMS 2469A, 30 June 1964.
13. "Lubricant, Solid Film", MIL-L-25504A, 28 July 1959.
14. "Enamel, Alkyd, Lustreless", TT-E-529A, 23 October 1959.
15. "Maintenance Engineering Requirements for CBR Developmental Equipment", EP-2, US Army Edgewood Arsenal, November 1963.

16. "Quality Program Requirements", MIL-Q-9858A, 16 December 1963.

17. "Drawings, Engineering and Associated Lists", MIL-D-70327, 1 July 1959.

18. "Specifications, Contractor Proposed; Instructions for the Preparation of", Chemical Corp Purchase Description 197-54-820, 8 January 1962.

19. "Standardization Policies, Procedures and Instructions", Defense Standardization Manual, M200A, AR 715-10, April 1962.

20. "Requirements for New Equipment Training for Edgewood Arsenal Developmental Equipment", US Army Edgewood Arsenal, MEP-40, February 1965.

21. "Preservations, Methods of", Military Specification, MIL-P-116D, December 1962.

22. "Preservation Packaging, and Packing of Military Supplies and Equipment", Defense Supply Agency, TM 38-230, December 1963.

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APPENDIX B

DEVELOPMENT TEST RESULTS

A INTRODUCTION

The following abstracts of development tests of the E49 Filter Unit and components were prepared by Environ Laboratories, Inc., Minneapolis, Minnesota, an independent test agency which performed the given tests. A detailed analysis is contained in ''.I Engineering Report No. 2437 and No. 2639.

B SHOCK TEST - E67 CONTROL PANEL

1 Object

To subject one (1) Control Panel, Donaldson Model E67, submitted for testing by Donaldson Company, Inc., to the Shock Test per MIL-STD-810 (USAF) dated 14 June 1962, Method 516, Procedures I and II.

2 Conclusions

Visual examination of the test unit during the non-operating test showed no evidence of damage except in two (2) of the shock positions. After the shock pulses to the right side of the test unit, the ALARM-OFF Solenoid Switch Assembly was found to be unsnapped. The damage was corrected and the Shock Test continued. Following the top position shock pulses, the ALARM-OFF Solenoid Switch Assembly and the UNIT ON Switch Assembly were found unsnapped. The faults were corrected and the Shock Test continued. Visual examination during and after the operation shock showed no evidence of damage to the unit.

C SAND AND DUST TEST - E67 CONTROL PANEL

1 Object

To subject one (1) Control Panel, Donaldson Model E67, to the Sand and Dust Test of Paragraph III, Development Test Plan, Contract DA-18-035-AMC-100(A), dated 16 June 1965.

2 Conclusions

Visual examination of the test specimen following the test revealed no evidence of damage resulting from the test.

Operational checks prior to and following exposure were conducted by Donaldson Company, Inc., personnel.

D OPERATING VIBRATION TEST - E67 CONTROL PANEL

One (1) Model E67 Control Panel, Gas-Particulate Filter Unit, was subjected to sinusoidal vibration at -65°F and under room ambient conditions in each of its three (3) mutually perpendicular axes.

During vibration, in the vertical axis, it was noted, after an hour at -65°F, the Flow Light had become unscrewed in its socket and the ALARM OFF switch did not function.

During vibration, in the transverse axis, it was noted, after an hour at -65°F, the Circuit Breaker Lights ground wire was broken and there was a crack in the rear of the plastic assembly of the Firing Mode Switch .

During vibration, in the transverse axis, it was noted, after the second hour at room ambient temperature, the Max Light did not operate.

Repairs were made at these times by Donaldson Company personnel. Upon completion of the test, the control panel was returned to Donaldson Company, Inc., for post vibration evaluation.

E HUMIDITY TEST - E67 CONTROL PANEL

1 Object

To subject one (1) Control Panel, Donaldson Model E67, submitted for testing by Donaldson Company, Inc., to the Humidity Test per Appendix B1, Statement of Work, Contract DA-18-035-AMC-100(A), dated 16 June 1965.

2 Conclusions

Visual examination of the test specimen following the test showed no evidence of damage resulting from the Humidity Test.

Operational checks made during and after the test were conducted by Donaldson Company personnel.

F NONOPERATING VIBRATION TEST - E49 FILTER UNIT

One (1) Model E49 Gas-Particulate Filter Unit was subjected to sinusoidal vibration at -65°F, +155°F and under room ambient conditions in each of its three (3) mutually perpendicular axes.

No apparent damage was noted at the completion of this test. The filter unit was turned over to Donaldson Company, Inc. personnel for post vibration evaluation.

G OPERATING VIBRATION TEST - E49 FILTER UNIT

One (1) Model E49 Gas-Particulate Filter Unit was subjected to sinusoidal vibration at room ambient conditions only in each of its three (3) mutually perpendicular axes.

A lead wire broke and an electrical connector fractured during the longitudinal axis of this test. No other damage was noted either during or at the completion of this test. The unit was returned to Donaldson Company, Inc., for post vibration evaluation.

H HUMIDITY TEST - E49 FILTER UNIT

1 Object

To subject one (1) Filter Unit, Gas-Particulate, Tank, EMD, 400 CFM, E49, Serial No. 1059601A89, submitted for testing by Donaldson Company, Inc., to the Humidity Test per Appendix B1, Statement of Work, Contract DA-18-035-AMC-100(A), dated 16 March 1964.

2 Conclusions

Visual examination of the test specimen following the test showed no evidence of damage resulting from the Humidity Test.

Operational checks made during and after the test were conducted by Donaldson Company personnel.

I SHOCK TEST (NONOPERATING AND OPERATING) - E49 FILTER UNIT

1 Object

To subject one (1) Filter Unit, Gas-Particulate, Tank, EMD, 400 CFM, E49, Serial No. 106 9601 A83, submitted for testing by Donaldson Company, Inc., to the Shock Test per MIL-STD-810 (USAF) dated 14 June 1962, Method 5 , Procedures I and II.

2 Conclusions

Visual examination of the test unit during the non-operating test showed no evidence of damage until the last position (top). The gas pack pivot pin was sprung, causing binding and misalignment of the assembly. The problem was corrected and the Shock Test continued under operating conditions. Visual examination during and after the operation shock showed no evidence of further damage to the test unit.

J BAROMETRIC PRESSURE TEST - E49 FILTER UNIT

1 Object

To subject one (1) Filter Unit, Gas-Particulate, Tank, EMD, 400 CFM, E49,

Serial No. 105 9601 A89, submitted for testing by Donaldson Company, Inc., to the Barometric Pressure Test per MIL-STD-810 (USAF) dated 14 June 1962, Method 500, Procedure I.

2 Conclusions

Visual examination of the test specimen following the test showed no evidence of damage resulting from the Barometric Pressure Test.

Operational checks made during and after the test were conducted by Donaldson Company, Inc., personnel.

APPENDIX I

QUALITY ASSURANCE REVIEW - CHICAGO PROCUREMENT DISTRICT

The following reports were prepared by the Chicago Procurement District Area Resident Inspector. This agency was designated by the Government to monitor and provide assistance with performance of the Quality Assurance Program for Contract DA-18-035-AMC-100(A).

AMXCH-IM — QAR Progress Report, DA-18-035-AMC-100 (A) Donaldson, Minneapolis, Minn.

Quality Assurance Directorate
Edgewood Arsenal, Maryland

P. Krueger, QARIC, DCI — 2 Aug 1965
NW Area Insp Office
Minneapolis, Minn

1. Development testing of the filter unit and the control panel assembly is now completed. Testing was conducted at Donaldson Co., Inc, and at Einviron Labs.

a. Tests conducted at DCI were the erosion test on the fan assembly, and the dust efficiency tests. The assembly was loaded with silicon dust and the motor brushes burned out after 213 hours. Further analysis of failure was performed by the motor manufacturer. Visual inspection of the fan housing and impeller disclosed no excessive loss due to errosion. It was anticipated that a rerun was to be made with a new motor but this test will be included in the reliability test scheduled for July and August. Dust efficiency tests were run and results indicated 92% + efficiency.

b. Environ Laboratory Testing:

Humidity and barometric tests were performed and the unit met the requirements of the design data. Non-operating drop testing of the unit at 30 G's acceleration was completed and only damage that occured was that the shock pad bent during the vertical top-down test drop. This was repaired and retested. Unit passed requirements. Operational tests during drop were performed and no malfunction occured. Test results were satisfactory.

Vibration testing in three planes were performed non-operating at low and high temperatures. No problems were encountered. During the operating test period at normal ambient and vibration, a failure of the flow control occured and the flow control opened up to full flow. A correction of this problem was made by DCI and will be incorporated in future units.

2. Present Status: DCI has placed orders for most of the material to be incorporated into the pilot lot units. Material now being received and assembly of the smaller sub-assemblies, and a few major assemblies. Inspection of items is being made in accordance with letter of instructions issued by your office. Inspection results are being kept for each item inspected, listing those characteristics checked. Certification of material, and finish is being accepted for those items. Vendors and treatment facilities are furnishing those certificates.

3. Reliability Demonstration: Unit started on reliability demonstration at 11:35 AM 10 July, and shut down on 26 July 4:00 PM (500 hours includes 105 hours previous operation. Unit was shut down to perform routine maintenance support. Unit presently shut down, it is anticipated that this period will be completed during August.

P. A. KRUEGER
QARIC

AMXQE-IM

Progress Report, DA-18-035-AMC-100(A)
Donaldson Co., Inc., Minneapolis, Minn

Quality Assurance Directorate
Edgewood Arsenal, Maryland

P. A. Kruegor, QARIC, DCI 20 Aug 65
NW Area Insp Office
Minneapolis, Minn Covers Period: 1-15 Aug.

1. Reliability Demonstration: Unit still shut down awaiting return of motor from mfgr who was to turn down the commutator to meet requirements for concentricity. Motor to be returned week of 16 August, and will be reinstalled and testing will continue.

2. Assembly of units on contract: Dilivery of the parts for the 12 units is now approximately 98% completed. Government inspection personnel are conducting inspection on these parts and assemblies to the Class A drawings. Many assemblies are now in process of assembly, and nearing completion. Deep fording valve assemblies are 100% completed, and tested. The filter housings are being fabricated and 6 each are completed and accepted for further assembly. Four fan motor assemblies are in route from the fan mfgr., and are expected here during week of 16 Aug.

Inspection results to date indicate that the manufactureres inspection is insuring compliance with the class A drawings. No assemblies or parts, which were passed by the contractor's inspectors have been found defective, however, the contractor is processing a deviation request on the raised bead for a hose connection tube.

3. Contract presently plans to meet the delivery requirements of the contract. Contractor is proceeding with assembly and tests on assemblies as they are completed.

P. A. KRUEGER,
QAR

AMXCH-EM

DA-18-035-AMC-100(A), Donaldson Co., Inc.

Quality Assurance Directorate
Edgewood Arsenal, Maryland
Attn: John Moyer

P. Krueger, QAR

31 August '65

1. Reference is made to phone request for evaluation of the quality of the material being procured to the Class A drawings on subject contract. Inspection of the parts and assemblies are being made to the drawings by Govt. inspection personnel as requested. Inspection of individual parts is now completed, and the contractor is proceeding with the assembly of the unit. Government inspection is now being applied to those assemblies after the contractor has complotted assembly, and any required adjustment or test.

2. Inspection by the Government has revealed that the contractor has exercised excellent control on the material recieved for use on this contract. Parts have all been within the tolerances on the drawings and to date no evidence of faulty inspection by the contractor has been noted. There have been items which were rejected by the contractor, and returned to the source for correction or replacement, but in all of these cases rejection was by the contractor's inspection personnel. One item is now being used on which deviation from the MS drawing specified on the Class A drawing, is being processed by the contractor.

3. Check out of the gaskets was primarily limited to the form, and where a mating recess was used, those parts were assembled to the part for a check on the correctness of fit. Certification is on hand for the materials in the gasket. Visual inspection was performed on the cover coat on the sponge rubber gaskets to insure completeness of the cover.

4. The contractor has, or has requested certification on the materials and special finishes applied to the parts. Where a special material or finish was noted on the drawing, those items were included as characteristics on the Government CD.

5. For the large housing assembly and the inlet air casting Government inspection was performed at the same time the contractor made his inspection since those involved time consuming surface plate set-ups.

6. Certified welders were utilized by the contractor and check was made on the welding to insure that these men were the ones performing the welding.

7. Check of the fording valve assembly setting was made at the time the contractor set the limit switches. Go and Not-Go gages were utilized for checking correctness of the setting, and the time for closing of the valve was checked by electric timer.

8. Regarding the evaluation of the contractor's O&M manual and the test fixture for leak detection, this will be performed during the period 15-30 Sept. Performance of this evaluation will be with the view of someone unfamiliar with the unit, and performing the maintenance procedures as written in the manual.

P. A. KRUEGER, QAR, CHPD.

AMXCH-IM

Progress Report, DA-18-035-AMC-100A
Donaldson Co., Inc., Minneapolis, Minn

Quality Assurance Directorate
Edgewood Arsenal, Md.
THRU: CHPD, US ARMY
Chicago, Ill

P. Krueger, QARIC
NW Area Inspection Office
Minneapolis, Minn

17 Sept 65

Covers Period 1-15 Sept

1. Reliability Demonstration: Unit operating on test cycle of the PD, Unit how has approximately 1125 hours of operation. Operation is continuing with the scheduled length of the run to be 1760 hours. No problems have occured to date since start of this period of operation after inspection and maintenance on the 500 hour interval.

2. Assembly of Filter Units: Major assemblies now nearing completion. Inspection of the units has been to the Govt. drawings and no discrepancies noted to date. Motor-fan assemblies are completed and the assembly of the deep fording valves to the blower section is scheduled for completion during next 3 days. Blower-motor assemblies were checked out on the blower test fixture. All particulate filters were checked out by DCI, using DOP penetration method. Pressure drops were also recorded at various flows. These were within allowable limits and no DOP penetration was detected. The gas filter packs have been completed and are now sealed in bags awaiting shipments

3. Test equipment is being completed and the operational manuals will be available during the week of 20 Sep 65 for use in evaluating test procedure instructions. It is planned that Govt. personnel will use this draft copy of the instructions for opeation of the test equipment. Report of findings on this evaluation will be reported as requested by Mr. Moyar.

P. A. KRUEGER
QARIC

DCRS-DTQP 6 Oct 1965

SUBJECT: Final Quality Assurance Evaluation Report, Contract DA-18-035-AMC-100 (A), Donaldson Co., Inc., Minneapolis, Minnesota

TO: Contracting Officer
U. S. Army Edgewood Arsenal
Edgewood Arsenal, Maryland
ATTN: Mr. Moyer

Following is subject report submitted by Philip A. Krueger, QAR, for the period 15-30 September 1965:

a. Material covered by subject contract is complete and ready for shipment. Material is being held by the contractor for final shipping instructions from the Contracting Office.

b. Assemblies were checked out with the inspection aids for operation, and inspection was made to Class A drawings prior to testing.

c. The quality maintained by the contractor during this contract was excellent and tight control was exercised over the production personnel by the contractor's Quality Control organization.

FOR THE CHIEF:

RAYMOND E. COLES
Chief, Quality Assurance Division

MEMORANDUM FOR RECORD: Required per letter of delegation. This is final report.

P.R. Krueger/edg/252/6 Oct 65

DCRS-DTQP 6 Oct 1965

SUBJECT: Inspection Report of Evaluation of the Contractor's Operational Manual for Inspection Aids, Contract DA-18-035-AMC-100 (A), Donaldson Co., Inc., Minneapolis, Minnesota

TO: Contracting Officer
U. S. Army Edgewood Arsenal
Edgewood Arsenal, Maryland
ATTN: Mr. Moyer

Following is subject report submitted by Philip A. Krueger, QAR:

a. Inspection Aids listed below were operated based on the contractor's operational instructions. Inspection Aids checked were:

(1) Leak testing of housing
(2) Deep fording valve check-out fixture
(3) Control panel operational test panel
(4) Fan assembly test chamber
(5) Precleaner operational check-out panel

b. Operation of the test equipment in accordance with contractor's instructions uncovered a few errors in numbering of steps or condition of indicator lights. The necessary corrections were made to the instructions and inspection aids were operated satisfactorily.

c. The balance of the inspection aids are of such a nature that they are adaptors for test equipment at Government facilities. These fixtures and adapters are completed; however, no checking of the operational manual was performed.

FOR THE CHIEF:

RAYMOND E. COLES
Chief, Quality Assurance Division

MEMORANDUM FOR RECORD: Required per fonecon request, Mr. Moyer, CRDL, Edgewood Arsenal.

P.R. Krueger/edg/252/ 6 Oct 65

UNCLASSIFIED
Security Classification

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13. ABSTRACT

The work summarized in this final comprehensive report covers 25 mo of design and development of a 400-cfm gas-particulate filter unit for the proposed main battle tank. Design and experimental data for this program is completely detailed in report 1 through 19, including a design study report, feasibility study report, and a blast hazard test supplement. This report summarizes design concepts, preproduction model E49 filter unit design, performance and development test results, engineering services activity, and contract coordination throughout the program.

14. KEYWORDS

CP vehicles	Gas filter	Antiblast closure
Filter unit	Particulate filter	Main battle tank
	Collective protector unit	EMD gas particulate, 400 cfm

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